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HISTORIC TRENDS IN THE SECCHI DISK TRANSPARENCY OF LAKE PONTCHARTRAIN

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ABSTRACT A major environmental concern about Lake Pontchartrain is an assumed long-term increase in turbidity based on Secchi disk transparency observations. Regression of the available data on Secchi disk transparency versus time (1953 through 1990) reveals a statistically significant decrease in transparency of about 40%. However, the data set is biased in that it does not adequately represent the seasonal effects of salinity and wind speed. Two analytical procedures were undertaken to determine the extent to which the apparent long-term decrease in transparency was dependent on the seasonal bias. One procedure involved seasonal adjustment of the data for the effects of salinity and wind speed. The other procedure was to remove the seasonal bias by constructing unbiased data sets.

Seasonal adjustment for the effects of salinity and wind speed reduced the level of significance for the relationship between Secchi disk transparency and time from about 1% to about 10%. This result indicates that some of the apparent decrease in transparency in the original data is the result of inadequate representation of seasonal effects in the biased data set.

In most years data are not available for all months with the result that the seasonal effects of salinity and wind speed are not adequately represented. When the bias was removed by constructing unbiased data sets, the data no longer supported the conclusion of a statistically significant change in Secchi disk transparency from 1953 to 1990; $p > 0.5$.

INTRODUCTION

Lake Pontchartrain is an embayment in a large estuarine system in southeastern Louisiana. It has a mean salinity of 4 ppt, a mean depth of 3.7 m, and a surface area of 1630 km². Saline water enters from adjacent estuaries through tidal passes. Fresh water sources are streams, New Orleans area outfall canals, and the Mississippi River during opening and leakage of the Bonnet Carré Spillway (Barbé and Poirrier, 1991).

Over one million people live on the southern shore of Lake Pontchartrain. With increasing urbanization of the New Orleans area over the last century, concerns have arisen as to possible declines in water quality, fisheries, recreational use and commercial value of the estuary (Houck *et al.*, 1987). Increased turbidity, for example, is regarded as an environmental problem in Lake Pontchartrain. Support for that concern is provided by Stone *et al.* (1980) who plotted four sets of selected Secchi disk transparency data from Lake Pontchartrain and concluded that water clarity had decreased by almost 50% between 1953 and 1978.

Although Stone's report (Stone *et al.*, 1980) is often cited as indicating a major environmental change in Lake

Pontchartrain, it did not include all available data or address the seasonal effects of wind and salinity on transparency values. Thompson and Fitzhugh (1985) found a relationship between salinity and lake clarity with Lake Pontchartrain being clearer during periods of higher salinity and more turbid during fresher periods. Swenson (1980), found that winds blowing over Lake Pontchartrain are sufficient to stir and mix bottom sediments throughout the water column about 15% of the time. Thompson and Verret (1980) reported that occasional high winds during frontal passages, and at other times, are capable of resuspending bottom sediments, especially in the winter. Dow and Turner (1980) also stated that turbid conditions may be caused by weather fronts and their wind systems.

Storm-water runoff from the New Orleans area is currently discharged into Lake Pontchartrain without any treatment. Although the potential contribution of urban runoff to the pollution of estuaries has been recognized for some time, few studies have actually documented specific adverse effects (Odum and Hawley, 1987). On an annual basis, pollution from urban runoff can contribute more suspended solids and plant nutrients than any other pollution source (Scheaffer *et al.*, 1982). Urban runoff could

affect the Secchi disc transparency of Lake Pontchartrain through the introduction of plant nutrients which increase phytoplankton growth and by the introduction of suspended solids (Mancini and Plummer, 1987; Odum and Hawley, 1987).

It is currently assumed that the turbidity of Lake Pontchartrain has increased by almost 50% between 1953 and 1978 (Stone *et al.*, 1980) due to the activities of man. Our study includes recent data, investigates the effects of salinity, wind and seasonal differences on transparency and tests long-term trends for statistical significance. The study was designed to provide a better understanding of trends and how natural factors affect water clarity. Results of this study will provide realistic goals for the treatment of urban runoff in plans to restore Lake Pontchartrain.

MATERIALS AND METHODS

Description of the Database

The Secchi disc is widely used to estimate the depth of light penetration in aquatic habitats (Tyler, 1968). All data used in this study were obtained with a 20 cm disc with black and white quadrants. The raw data used in this study consisted of observations of Secchi disk transparency and

salinity recorded by several investigators during the periods shown in Table 1. This data set contains Secchi disk transparency and salinity data from July 1953 through December 1990. In some years, data are not available for several months. For most months, data were only collected once a month. Data collected by the Louisiana Department of Environmental Quality from 1985 through 1990 were recorded from the Causeway Bridge, which is about 20 feet above the water surface. Therefore, their transparency values may be lower because of the greater distance between the observer and the water surface. In summary, the data set is incomplete:

- It does not contain data for all years.
- It does not contain data for all months.
- It may not be representative of particular months because data were collected only once or twice a month.
- It is not consistent with regard to station location.

Wind data used in this study were taken at New Orleans International Airport from 1953 through 1990 and published in Local Climatic Data by the National Weather Service Meteorological Observation Office. The elevations at which the wind data were measured were not the same in all years. The data from January, 1953 to July, 1969 were taken at an elevation of 3 feet above the ground, and the others at an elevation of 4 feet.

TABLE 1
Sources of Secchi disk transparency and salinity data.

Investigators	Period	N*
Suttkus <i>et al.</i> (1954)	8/19/53 - 6/30/54	155
Stern and Stern (1969)	6/2/69 - 7/22/69	71
Dugas and Tarver (1973)	3/18/70 - 5/18/71	109
Tarver and Savoie (1976)	9/26/72 - 8/22/74	279
Poirrier <i>et al.</i> (1975)	7/17/73 - 11/1/73	73
Stone <i>et al.</i> (1980)	1/78 - 12/78	219
O'Hara and Capello (1988); Louisiana Department of Environmental Quality (LADEQ) (unpublished data)	3/31/82 - 11/29/82	456
	1/4/83 - 12/7/84	816
	7/8/85 - 8/14/90	311
Steimle and Associates (1985)		
Western lake	1/12/84 - 10/25/84	168
Eastern lake	2/16/84 - 11/1/84	149

*Number of observations

The salinity data set, STORET, obtained from the U.S. Army Corps of Engineers contains data from 1953 through 1980, and from 1986 through 1989. These data were only used in analysis of variance to determine the statistical significance of annual seasonality in salinity.

Statistical Methods

All criteria were met for application of parametric statistical methods. Simple and multiple regression analyses and the analyses of variance were performed according to standard procedures as described in Sokal and Rohlf (1981).

RESULTS

Annual means, standard deviations, standard errors, and coefficients of variation of Secchi disk transparency were calculated for each year in which Secchi disk transparency data were available and are presented in Table 2. The highest values of Secchi disk transparency occurred in 1953 and 1954 (Table 2). The lowest Secchi disk transparencies occurred from 1973 through 1983. This period was affected by Bonnet Carré spillway openings in 1973, 1975, 1979 and 1983. The greatest relative dispersion (coefficient of variation) was recorded in 1974 and 1978 during the period

TABLE 2
Statistics for annual Secchi disk transparency calculated from the original data set.

Year	N*	Secchi disk transparency (cm)					
		Mean	High	Low	SD*	SE*	CV*
1953	62	131.69	431	30	76.36	9.70	59.4
1954	93	133.00	366	30	84.57	8.76	63.2
1969	71	89.31	183	15	39.51	4.69	44.2
1970	72	144.15	304.8	45.72	66.57	7.85	46.2
1971	37	140.87	182.9	91.44	23.88	3.93	17.0
1972	44	114.60	274	15.2	52.40	7.90	45.7
1973	208	79.29	274.3	9.1	41.59	2.88	52.4
1974	100	63.70	243.8	9.1	54.20	5.42	85.1
1978	219	60.60	165	1.5	37.42	2.53	61.7
1982	456	100.71	236.22	30.48	36.36	1.70	36.1
1983	685	55.79	182.88	2.54	30.54	1.17	54.7
1984	448	70.35	347.98	5.08	39.64	1.87	56.3
1985	35	106.80	213.4	14	47.70	8.06	44.7
1986	60	109.50	302.3	30.5	53.10	6.86	48.5
1987	59	68.00	142.24	25	26.00	3.38	38.2
1988	59	79.65	203.2	15.24	40.88	5.32	51.3
1989	59	102.00	182.88	30.48	34.00	4.43	33.3
1990	58	85.57	152.4	30.48	34.81	4.57	40.7

* N = Number of Observations
SD = Standard Deviation
SE = Standard Error
CV = Coefficient of Variation

of spillway openings, although 1953 and 1954 also realized high relative dispersion. The lowest relative dispersion was recorded 1971.

Average annual Secchi disk transparency is plotted as a function time in Figure 1. The period of time represented in the graph is 38 years: 1953 through 1990. Specific years are indicated above each point in the graph. Linear regression analysis was performed on annual means. The slope of the regression line, -1.47 cm/year, is statistically significant; $0.01 < p < 0.02$. The regression line indicates an apparent decrease in Secchi disk transparency from about 130 cm in 1953 and 1954 to about 80 cm in 1990 -- an apparent decrease of about 40%.

The data set is biased in that it does not adequately represent the seasonal effects of salinity and wind speed, two variables that have significant effects on Secchi disk transparency.

Figure 2 shows the annual seasonality in salinity. It is a graph of average monthly salinity versus months of the year. The highest salinities occur in the fall (September, October and November) and the lowest salinities occur in

the spring (April, May and June). Monthly means are based on 32 years of data from the STORET data base (U.S. Army Corps of Engineers). That data base was used to test the validity of the apparent seasonality in salinity with analysis of variance. The ANOVA table for two-way analysis of variance without replication is presented in Table 3. The variance ratio, 21.18, exceeds the critical value for the test, 1.8, indicating that highly significant differences exist among monthly mean salinities, producing a highly significant annual seasonality in salinity.

Figure 3 shows the annual seasonality in wind speed. It is a graph of average monthly wind speed versus months of the year. The highest wind speeds occur in February and March and the lowest wind speeds occur in July and August. Monthly means are based on 38 years of data from the National Weather Service. That data base was used to test the validity of the apparent seasonality in wind speed with analysis of variance. The ANOVA table for two-way analysis of variance without replication is presented in Table 4. The variance ratio, 103.42, exceeds the critical value for the test, 1.8, indicating that highly significant

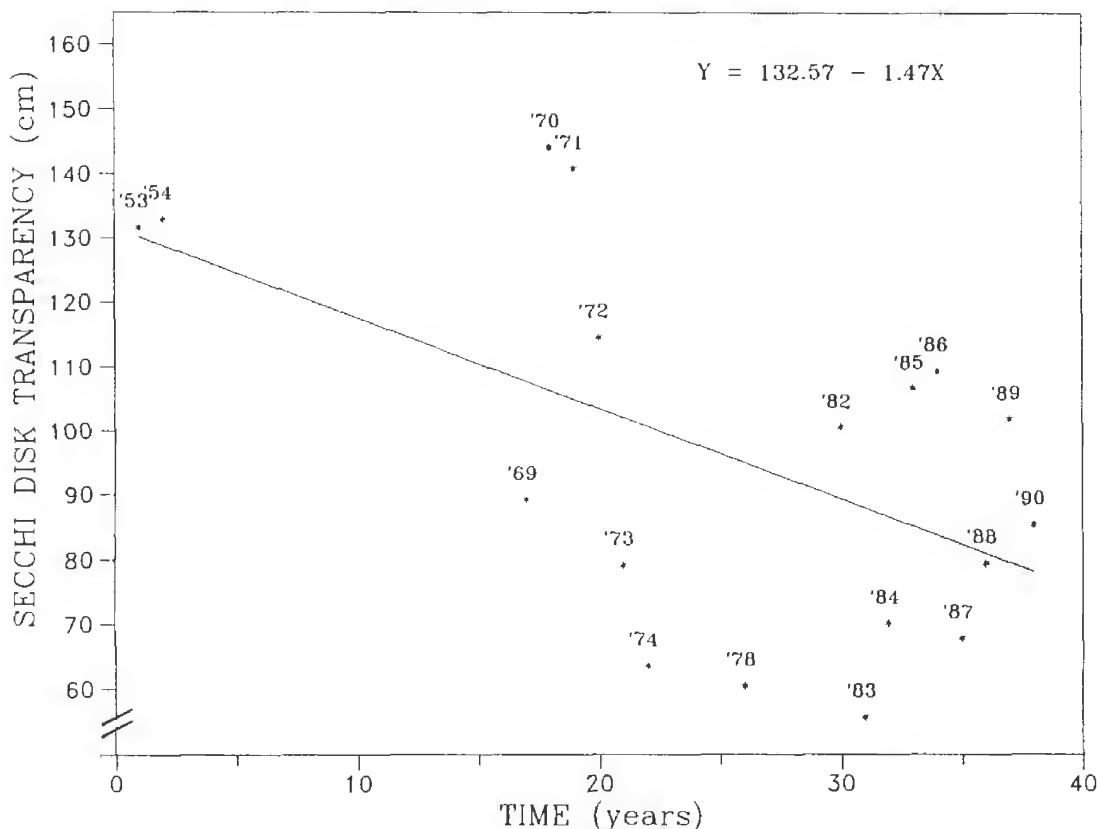


Figure 1. Annual mean Secchi disk transparency of Lake Pontchartrain from 1953 through 1990.

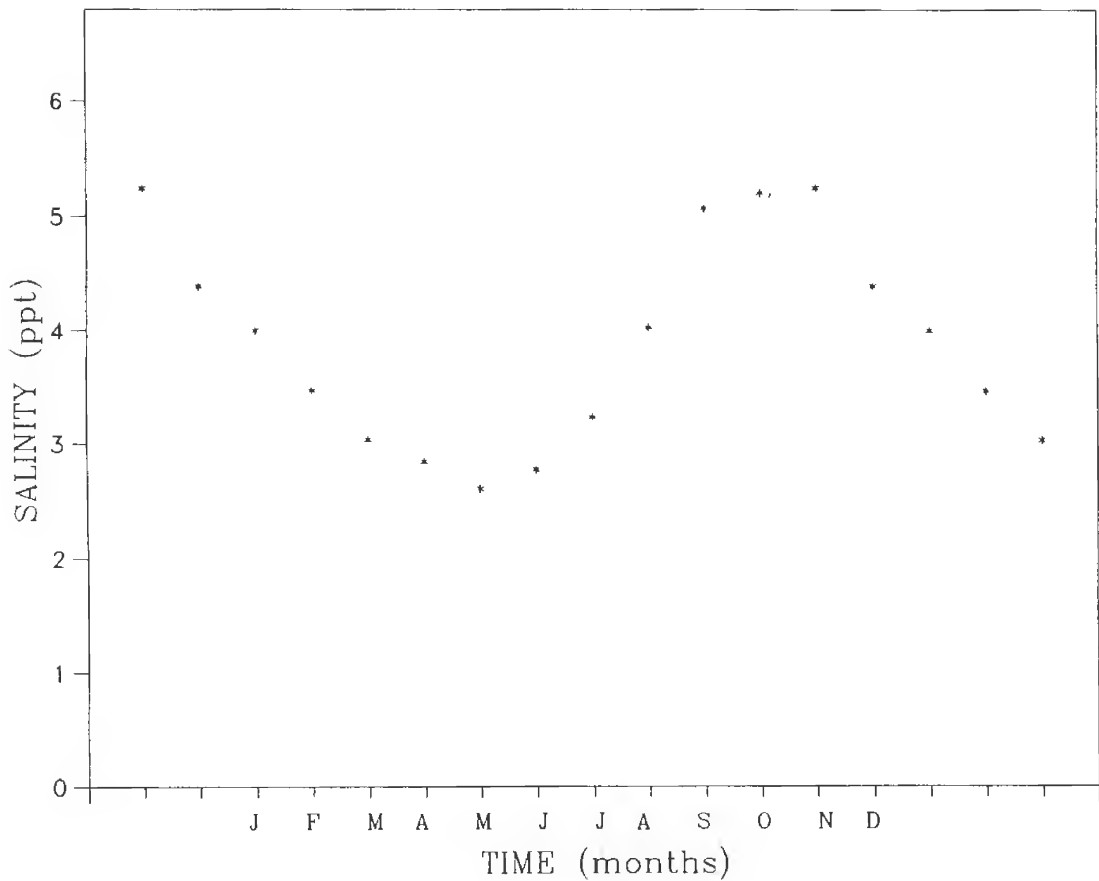


Figure 2. Monthly mean salinity.

TABLE 3
Analysis of variance of monthly mean salinity.

Source	SS	df	MS	F*
Month	333.77	11	30.34	21.28
Year	711.25	31	22.94	
Error	484.79	340	1.43	
Total	1529.81	38		

* F(0.95) = 1.8

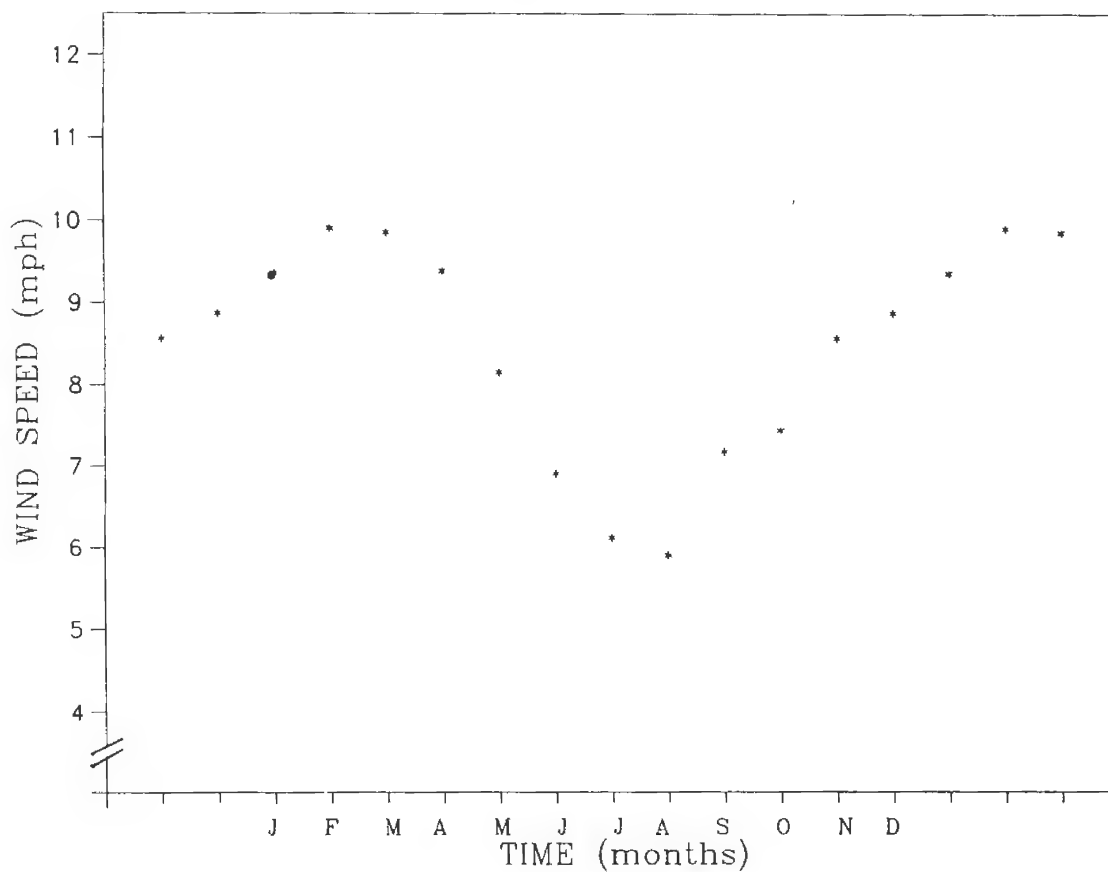


Figure 3. Monthly mean wind speed.

TABLE 4
Analysis of variance of monthly mean wind speed.

Source	SS	df	MS	F*
Month	825.50	11	75.05	103.42
Year	240.54	37	6.50	
Error	295.34	407	0.73	
Total	1361.38	455		

* $F(0.95) = 1.8$

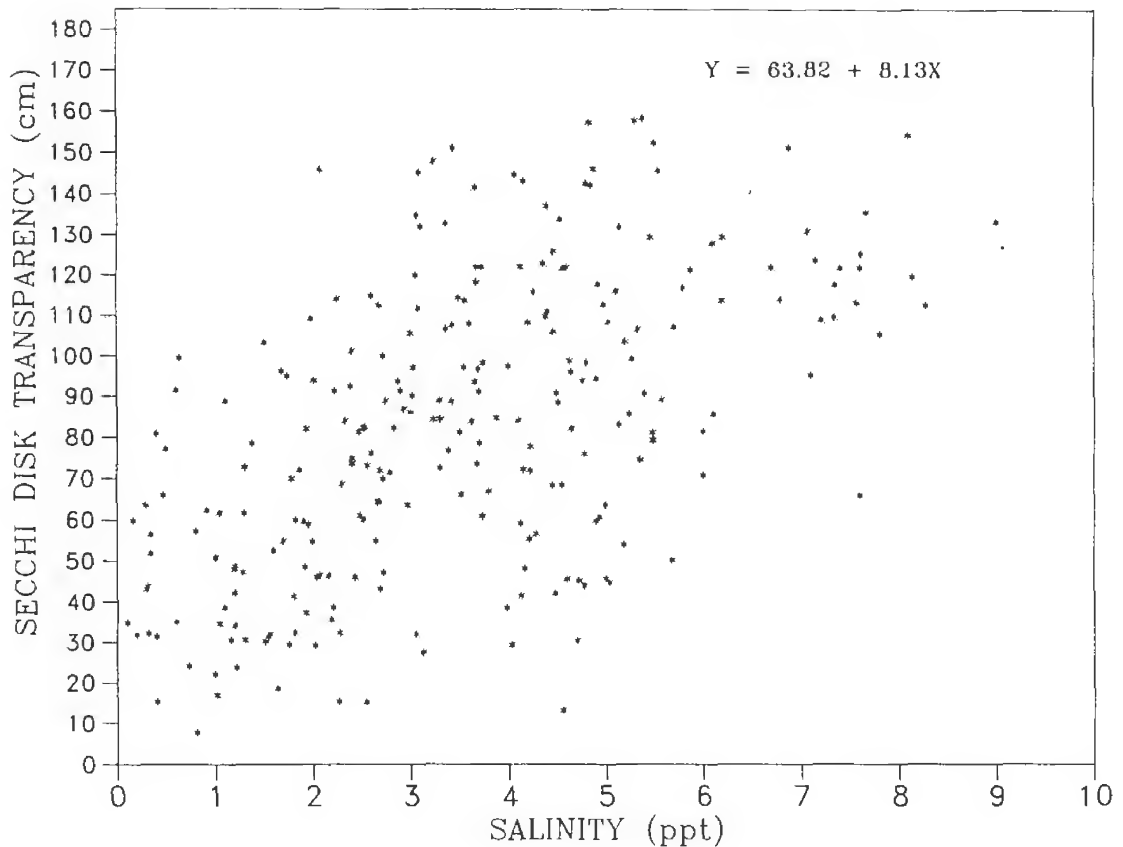


Figure 4. Secchi disk transparency (individual points) versus salinity.

differences exist among monthly mean wind speeds, producing a highly significant annual seasonality in wind speed.

Seasonal adjustment of the Secchi disk transparency data for salinity and wind speed was conducted in an effort to compensate for the seasonal bias in the data set. The adjustment for salinity is presented first.

Secchi disk transparency is plotted as a function of salinity in Figure 4. Salinity data are from the original data set. (Transparency values above 160 cm and salinity values above 10 ppt are not included in the graph.) Linear regression analysis was performed on individual points. The slope of the regression line, 8.13 cm/ppt salinity, is statistically significant; $0.01 < p < 0.02$. Figure 5 is a graph of average annual Secchi disk transparency plotted as a function of salinity.

Figure 6 is a graph of salinity versus time -- the 38-year period 1953 through 1990. Salinity data are from the original data set. Although there is considerable year-to-

year variation in salinity, there has been no long-term change in salinity. The slope of the linear regression line, -0.02 cm/year, is not statistically significant. The long-term average salinity, 3.9 ppt, was used as a base for seasonally adjusting the data for salinity.

There are two equivalent ways to seasonally adjust the Secchi disk transparency data. One way is to adjust annual means where annual mean Secchi disk visibilities and annual mean salinities are used in the calculation to provide adjusted annual mean Secchi disk visibilities. An equivalent procedure is to adjust individual points where individual Secchi disk transparency observations and associated salinities are used in the calculation; adjusted annual mean Secchi disk visibilities are then calculated from the adjusted points. Individual points are adjusted in the following example:

The adjustment procedure employed the regression equation presented in Figure 5 of Secchi disk transpar-

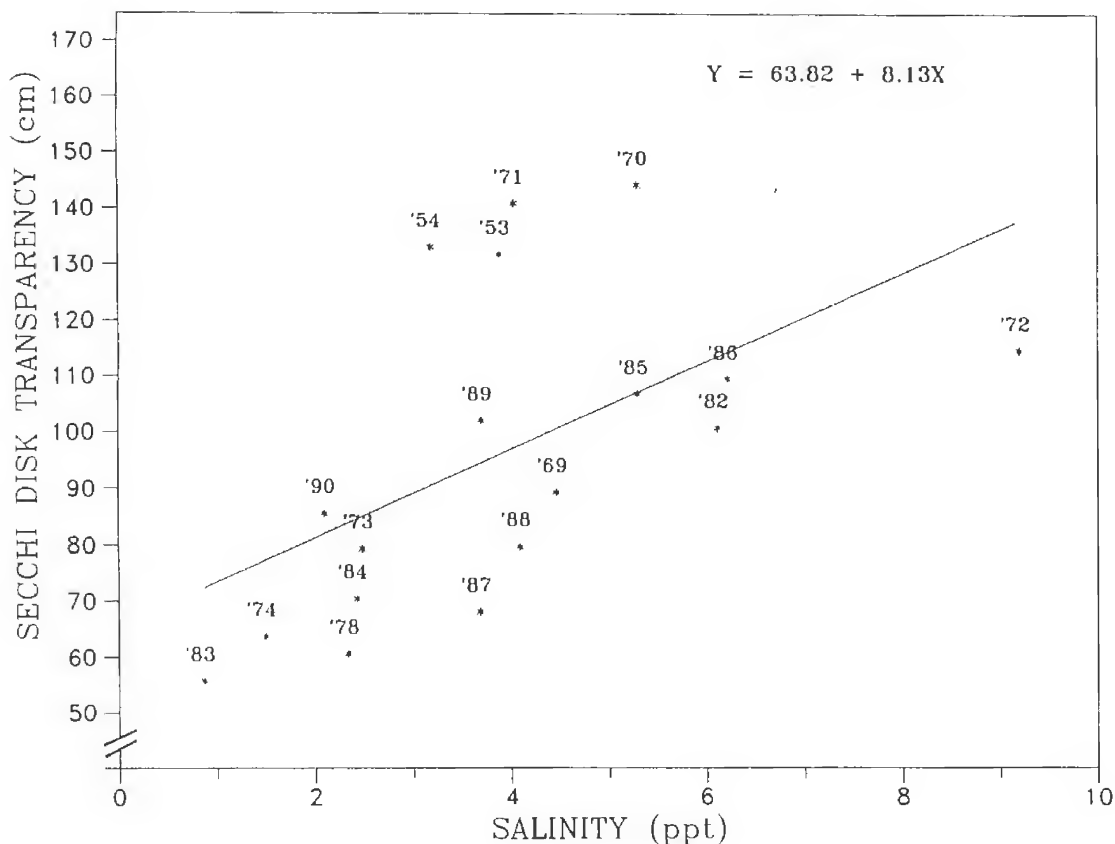


Figure 5. Annual mean Secchi disk transparency as a function of salinity.

ency versus salinity: $Y = 63.82 + 8.13X$. Two values of Secchi transparency were calculated for each point: (1) Secchi disk transparency using the long-term average salinity, 3.9 ppt; (2) Secchi disk transparency using the salinity associated with the specific point. The difference between those two values was the adjustment factor for that point. The adjustment factor was subtracted from Secchi disk transparency for that point. This operation adjusts the data to the long-term average salinity.

Figure 7 is a graph of annual mean Secchi disk transparency adjusted for salinity versus time. Comparison with Figure 1 reveals that very little change in slope has occurred -- 1.47 cm/year to -1.34 cm/year. The relationship between Secchi disk transparency and time is still significant at the 5% level, indicating that on average the Secchi disk transparency values in the original data set are not associated with unusually high or low salinities because of unequal representation of the seasonal effects of salinity in the data set.

Figure 8 is a graph of Secchi disk transparency versus wind speed. The graph includes Secchi disk transparency points in the original data set. (Transparency values above 160 cm are not included in the graph.) Wind speed is the five-day average of mean wind speed. Data are from the National Weather Service data set. Linear regression was performed on individual points. The slope of the regression line, -4.36 cm/mph, is statistically significant; $p < 0.01$.

Figure 9 is a graph of average annual wind speed versus time -- the 38-year period from 1953 through 1990. Although there is considerable year-to-year variation in wind speed, there has not been a long-term change in wind speed. Regression analysis was performed on annual means. The slope of the linear regression line, -0.02 mph/year, is not statistically significant. The long-term average wind speed, 8.13 mph, was used as a base for seasonally adjusting the data for wind.

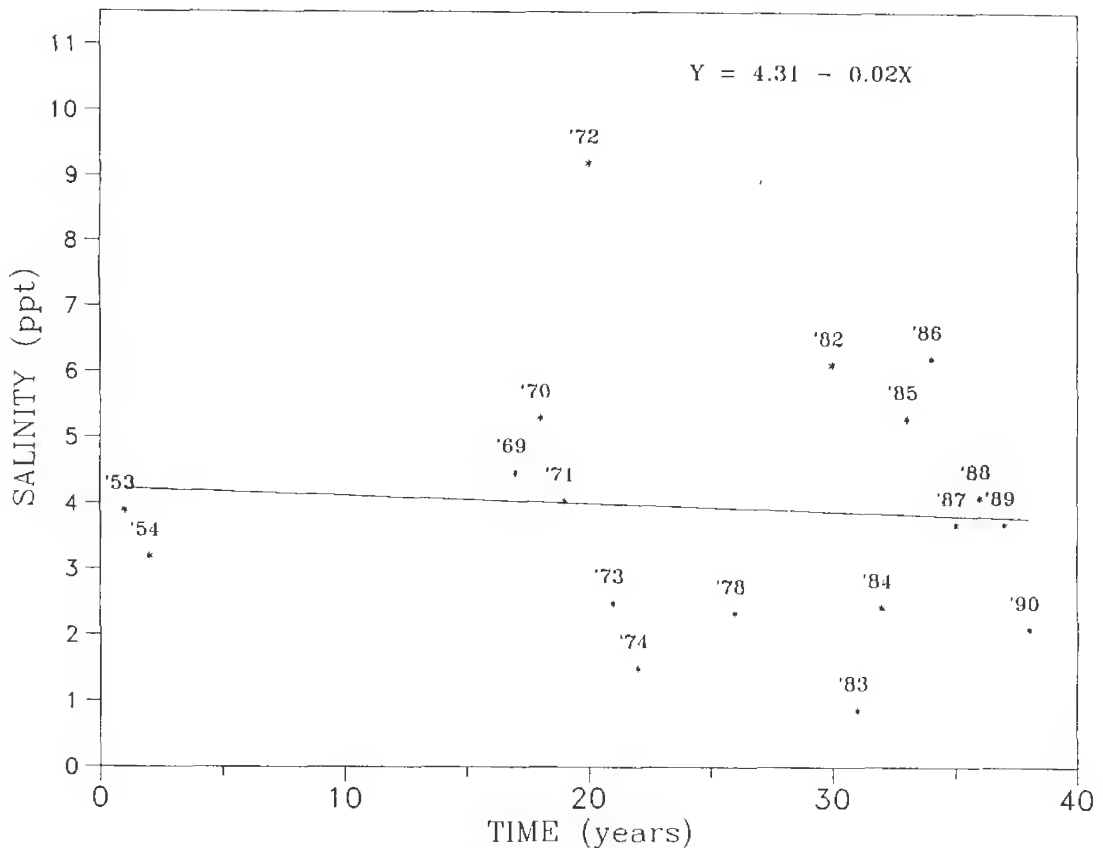


Figure 6. Annual mean salinity of Lake Pontchartrain from 1953 through 1990.

The adjustment procedure was the same as that described above for salinity. It employed the regression equation presented in Figure 7 of Secchi disk transparency versus wind speed; $Y = 121.43 - 4.36X$.

Figure 10 is a graph of Secchi disk transparency adjusted for wind speed versus time. Comparison with Figure 1 reveals that significant change in slope has occurred -- 1.47 cm/year to -1.06 cm/year. The relationship between Secchi disk transparency and time is no longer significant at the 5% level; $0.05 < p < 0.10$. This analysis determined that on an annual basis some Secchi transparency points were associated with unusually high or low wind speeds because of unequal representation of the seasonal effects of wind speed in the data set.

Multiple regression analysis was conducted with salinity and wind as independent variables and Secchi disk transparency as the dependent variable. Individual points were used in the analysis. The resulting regression equation was:

$$Y = 97.83 + 8.03 X_1 - 5.15 X_2.$$

Both partial regression coefficients are statistically significant. The long-term average salinity, 3.9 ppt, and the long-term average wind speed, 8.13 mph, were used as the base for seasonally adjusting the data for both salinity and wind speed. The adjustment procedure was the same as that described above for salinity. It employed the multiple regression equation shown above.

Figure 11 is a graph of Secchi disk transparency adjusted for both salinity and wind speed versus time. The relationship between Secchi disk transparency and time is no longer significant at the 5% level, but it is still significant at the 10% level; $0.05 < p < 0.10$. Seasonal adjustment has reduced the level of significance to about 10% (Figure 11). Therefore, one can conclude that some of the apparent decrease in Secchi disk transparency in the original data (Figure 1) is the result of unequal representation of the

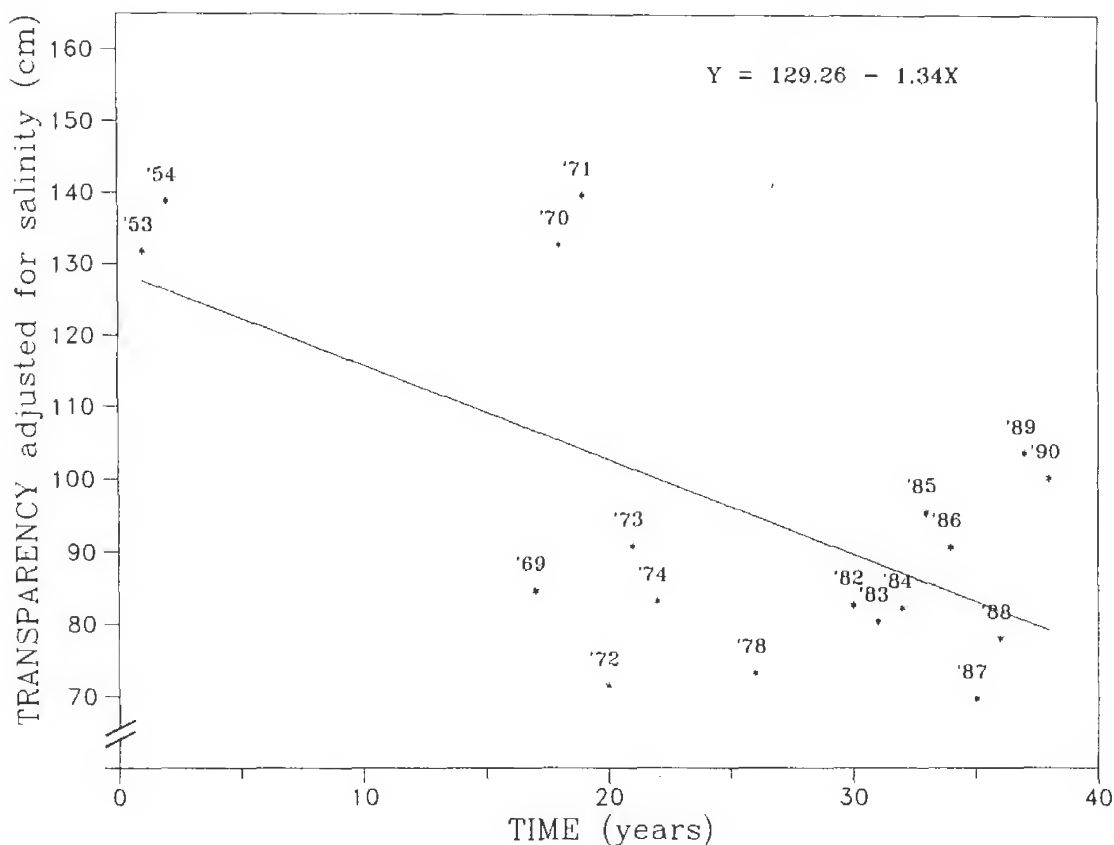


Figure 7. Annual mean Secchi disk transparency from 1953 through 1990 adjusted for salinity.

seasonal effects of salinity and wind speed in the biased data set.

Another analytical procedure undertaken with the original data set was to remove the seasonal bias by constructing unbiased data sets. There is not data in all 12 months of the year in most years represented in the data set. That is especially a problem in the earlier years. Only in the late 1980s are data consistently available for all 12 months of the year.

The Secchi disk transparency data set was, of course, subject to a seasonal bias in those years in which data were not available for all 12 months of the year. When the bias was removed by constructing unbiased data sets, the long-term relationship between Secchi disk transparency and time was no longer statistically significant. Three examples are provided:

Example 1. Table 5 contains Secchi disk transparency values for those years in which continuous data were available from August through December. This period was

TABLE 5
Secchi disk transparency for years in which data are available - August through December.

Year	Time (yr)	Transparency (cm)
1953	1	116.91
1970	18	149.64
1973	21	85.42
1978	26	81.93
1983	31	57.02
1985	33	119.29
1986	34	136.76
1987	35	78.23
1990	38	104.52

Regression transparency vs. time: $Y = 120.05 - 0.64X$
 $P > 0.5$

selected because in 1953 Secchi disk transparency readings were available only from August through December. It is not surprising that Secchi disk transparency was high in 1953 when one considers that salinity is highest in October and November (contributing to high transparency values), and that wind speed is lowest in August and September (also contributing to high transparency values). Other years have even higher average Secchi disk transparency values for the August through December period. Annual means in Table 5 were calculated by taking the average of monthly means rather than an average of all data points. Regression of annual Secchi disk transparency versus time produced the following equation:

$$Y = 120.05 - 0.64X.$$

The slope, -0.64 cm/year, is not statistically significant, $p > 0.5$. On the basis of this analysis, it is concluded that there has been no change in Secchi transparency over the 38-year period from 1953 through 1990.

Example 2. Table 6 contains Secchi disk transparency values for those years in which continuous data was available from January through June. This period was selected because in 1954 Secchi disk transparency observations were available only from January through June. The seasonal bias in the original data set was removed by constructing a data set consisting only of years in which Secchi disk transparency observations were recorded from January through June. Annual means in Table 6 were calculated by taking the average of monthly means rather than an average of all data points. Regression of annual Secchi disk transparency versus time produced the following linear regression equation:

$$Y = 75.13 - 0.49X.$$

The slope, -0.49 cm/year, was not statistically significant, $p > 0.4$. On the basis of this analysis, it is concluded that there has been no change in Secchi disk transparency over the 37-year period from 1954 through 1990.

Example 3. The original Secchi disk transparency data set, obtained by combining data from the sources indicated in Table 1, is incomplete. Data are missing for several months in most years. Table 7 includes all years for which there is at least some Secchi disk transparency data. Secchi disk transparency was estimated for those months in which data are not available -- the so-called missing months in the data set.

Missing data points were estimated with the multiple regression equation, $Y = 97.83 + 8.03 X_1 - 5.15 X_2$, and the appropriate monthly average wind speed and monthly average salinity. After estimating values for missing months, annual means for Secchi disk transparency were calculated for 1953 through 1990. Regression of annual

TABLE 6
Secchi disk transparency for years in which data are available - January through June.

Year	Time (yr)	Transparency (cm)
1954	2	97.46
1973	21	57.44
1974	22	47.55
1978	26	38.04
1983	31	29.95
1984	32	47.97
1986	34	80.65
1987	35	57.49
1988	36	65.28
1989	37	87.27
1990	38	64.58

$$\text{Regression transparency vs. time: } Y = 75.13 - 0.49X \\ P > 0.4$$

TABLE 7
Secchi disk transparency with estimated values in missing months.

Year	Time (yr)	Transparency (cm)
1953	1	94.89
1954	2	89.80
1969	17	87.13
1970	18	122.57
1971	19	101.54
1972	20	92.80
1973	21	75.37
1974	22	75.14
1978	26	59.12
1982	30	94.84
1983	31	43.86
1984	32	67.32
1985	33	91.71
1986	34	109.45
1987	35	67.48
1988	36	79.93
1989	37	102.23
1990	38	80.97

$$\text{Regression transparency vs. time: } Y = 95.52 - 0.42X \\ P > 0.5$$

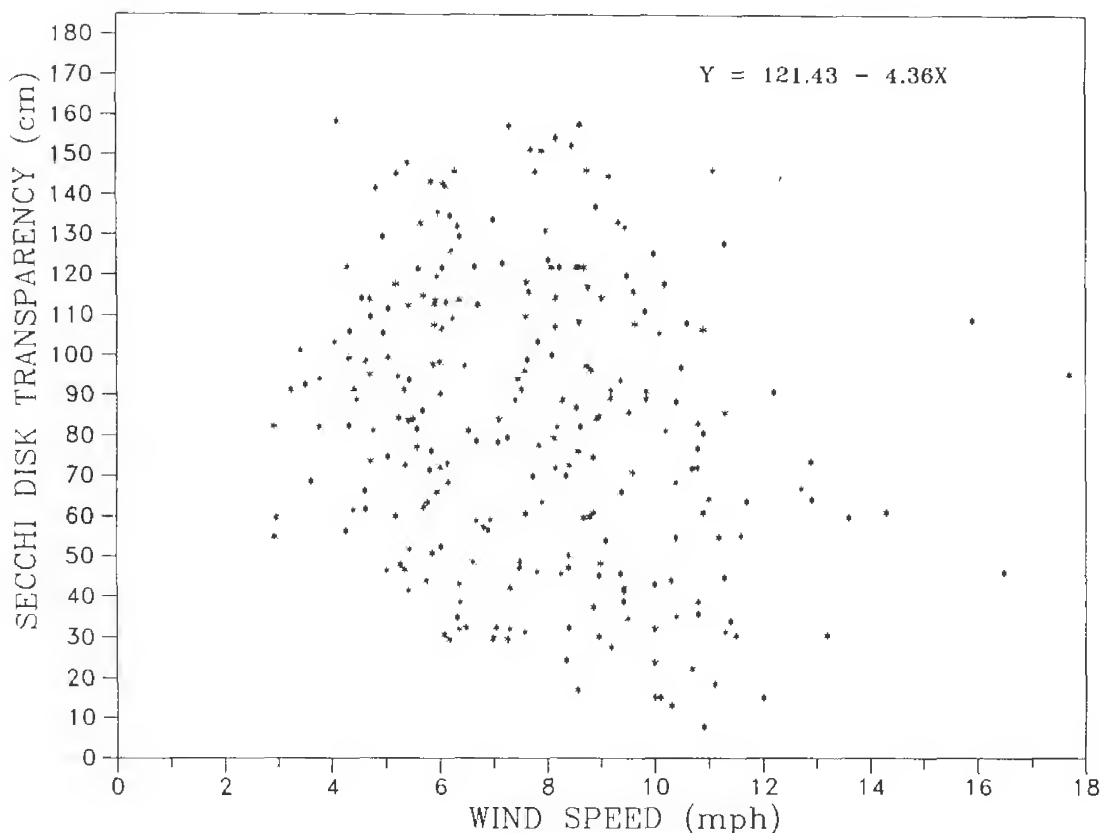


Figure 8. Secchi disk transparency (individual points) versus wind speed.

Secchi disk transparency versus time produced the following linear regression equation:

$$Y = 95.52 - 0.42X.$$

The slope, -0.42 cm/year, is not statistically significant, $p > 0.5$. On the basis of this analysis, it is concluded that there has been no change in Secchi transparency over the 38-year period from 1953 through 1990.

In summary, the historic data set on Secchi disk transparency in Lake Pontchartrain is biased in that it does not adequately represent the seasonal effects of salinity and wind speed. When the seasonal bias is removed from the data, it no longer supports the conclusion of a long-term decrease in Secchi disk transparency.

DISCUSSION

Regression of the original data on Secchi disk transparency versus time (1953 through 1990) reveals a statistically significant decrease in transparency with time. The regression line suggests a decrease in transparency of about 40%. However, the original data set is biased in that it does not adequately represent the seasonal effects of salinity and wind speed. The data set was subjected to two analytical procedures to determine the extent to which the apparent long-term decrease in Secchi disk transparency was dependent on the seasonal bias. One procedure involved seasonal adjustment of the data for the effects of salinity and wind speed. The other procedure was to remove the seasonal bias by constructing unbiased data sets.

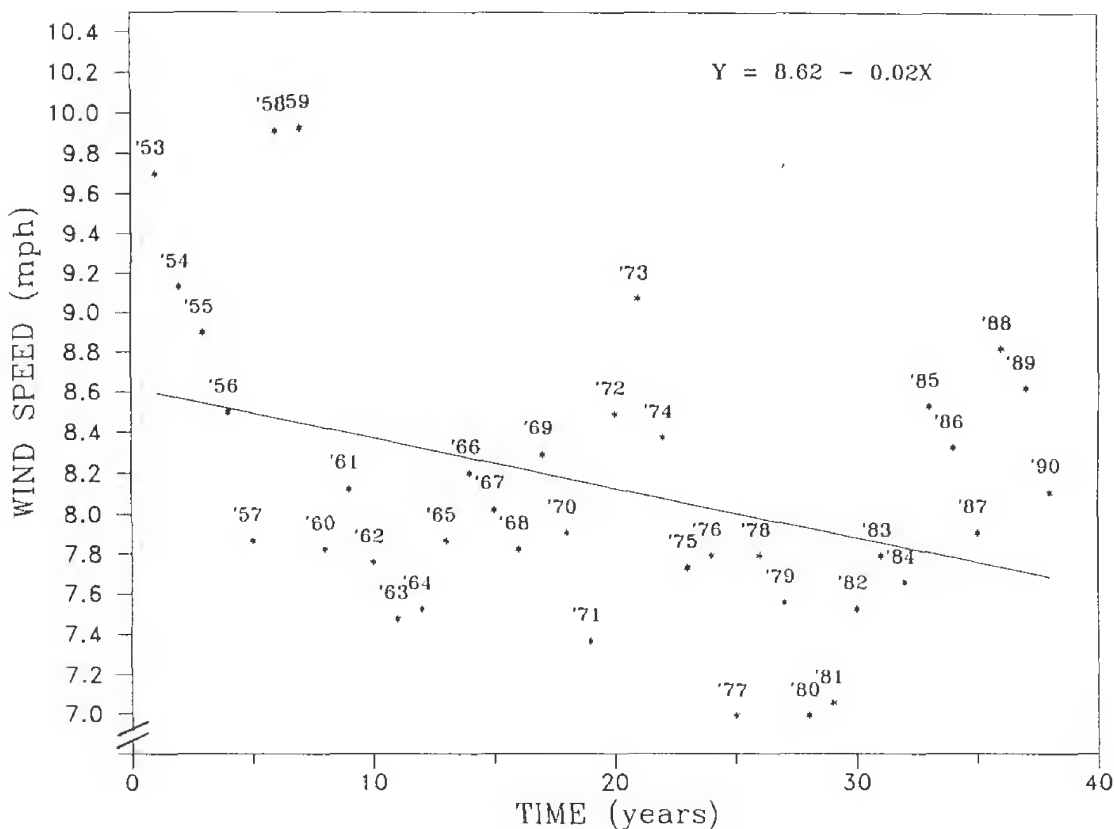


Figure 9. Annual mean wind speed for Lake Pontchartrain area from 1953 through 1990.

Regression analysis revealed a statistically significant, positive relationship between Secchi disk transparency and salinity, and a statistically significant, negative relationship between Secchi disk transparency and wind speed. Further analysis indicated that neither average annual salinity nor average annual wind speed had changed significantly from 1953 through 1990.

Secchi disk transparency data were seasonally adjusted for the effects of salinity and wind speed. The base for adjustment in each case was the long-term average of the variable for which adjustment was being made. Regression of Secchi disk transparency (adjusted for salinity) versus time revealed a statistically significant relationship, indicating that the adjustment procedure had not influenced the statistical significance of the long-term relationship between Secchi disk transparency and time. This result indicates that on average the Secchi disk transparency

values in the original data set are not associated with unusually high or low salinities because of unequal representation of the seasonal effects of salinity in the biased data set.

Regression of Secchi disk transparency (adjusted for wind speed) versus time indicated that there was no longer a statistically significant relationship between Secchi disk transparency and time; $0.05 < p < 0.10$. Adjusting the data for the effect of wind speed had reduced the level of significance for the relationship from about 1% to about 10%. This result indicates that some Secchi disk transparency values in the original data set are associated with unusually high or low wind speeds because of the unequal representation of the seasonal effects of wind speed in the biased data set.

Multiple regression of Secchi disk transparency (adjusted for both salinity and wind speed) versus time also

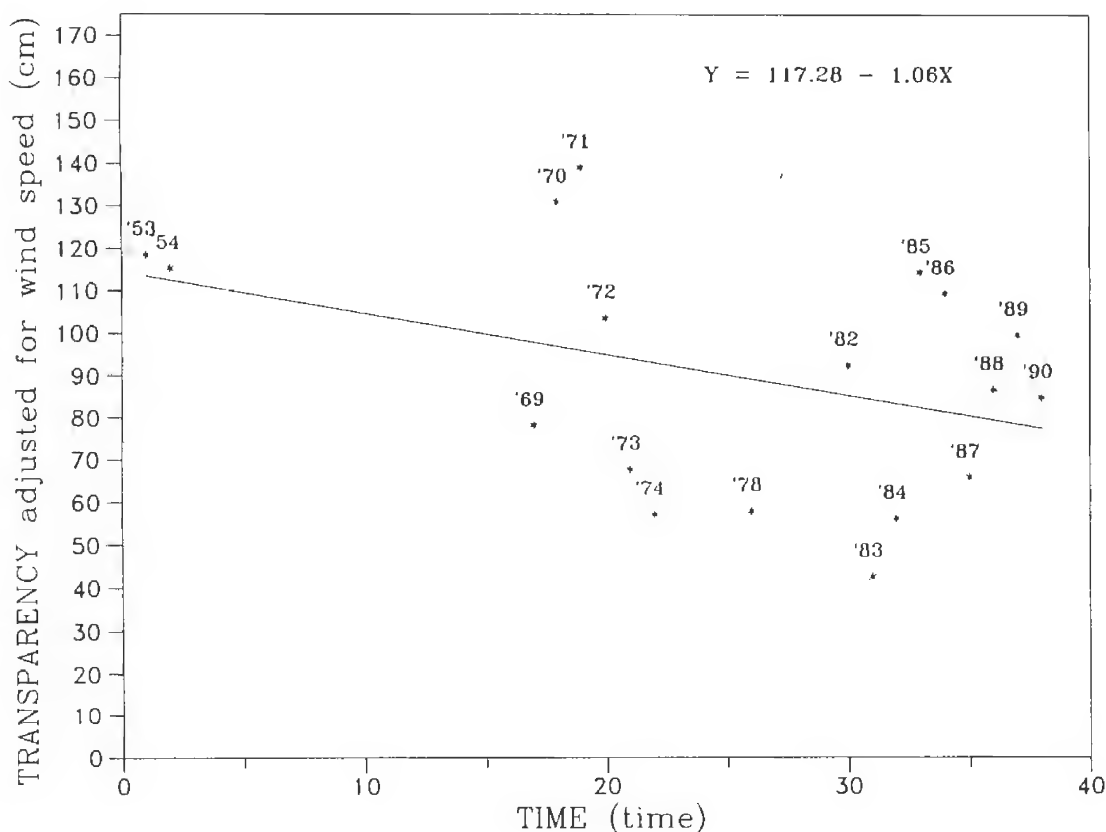


Figure 10. Annual mean Secchi disk transparency from 1953 through 1990 adjusted for wind speed.

indicated that there was no longer a statistically significant relationship between Secchi disk transparency and time; $0.05 < p < 0.10$. Seasonal adjustment had reduced the level of significance to about 10%. One can, therefore, conclude that some of the apparent decrease in Secchi disk transparency in the original data is the result of unusually high and low salinities and wind speeds realized because of unequal representation of the seasonal effects of salinity and wind speed in the biased data set.

Another analytical procedure undertaken with the original data set was to remove the seasonal bias by constructing unbiased data sets. In most of the years represented in the data set, data are not available for all 12 months of the year, especially before 1983. Only in the late 1980s are data consistently available for all 12 months of the year.

Analysis of variance of monthly salinity data from 1953 through 1980, and 1986 through 1989 (32 years) revealed a statistically significant annual seasonality, with the highest values occurring in November and the lowest values occurring in May. Similarly, analysis of variance of monthly wind speed data from 1953 through 1990 (38 years) revealed a statistically significant annual seasonality, with the highest values occurring in February and the lowest values occurring in August. These seasonal effects are not adequately represented in the available data on Secchi disk transparency in Lake Pontchartrain. The seasonal bias was removed from the data by constructing unbiased data sets in three ways: (1) The derived data set contained Secchi disk transparency values for those years in which continuous data were available from August through December; (2) The derived data set contained

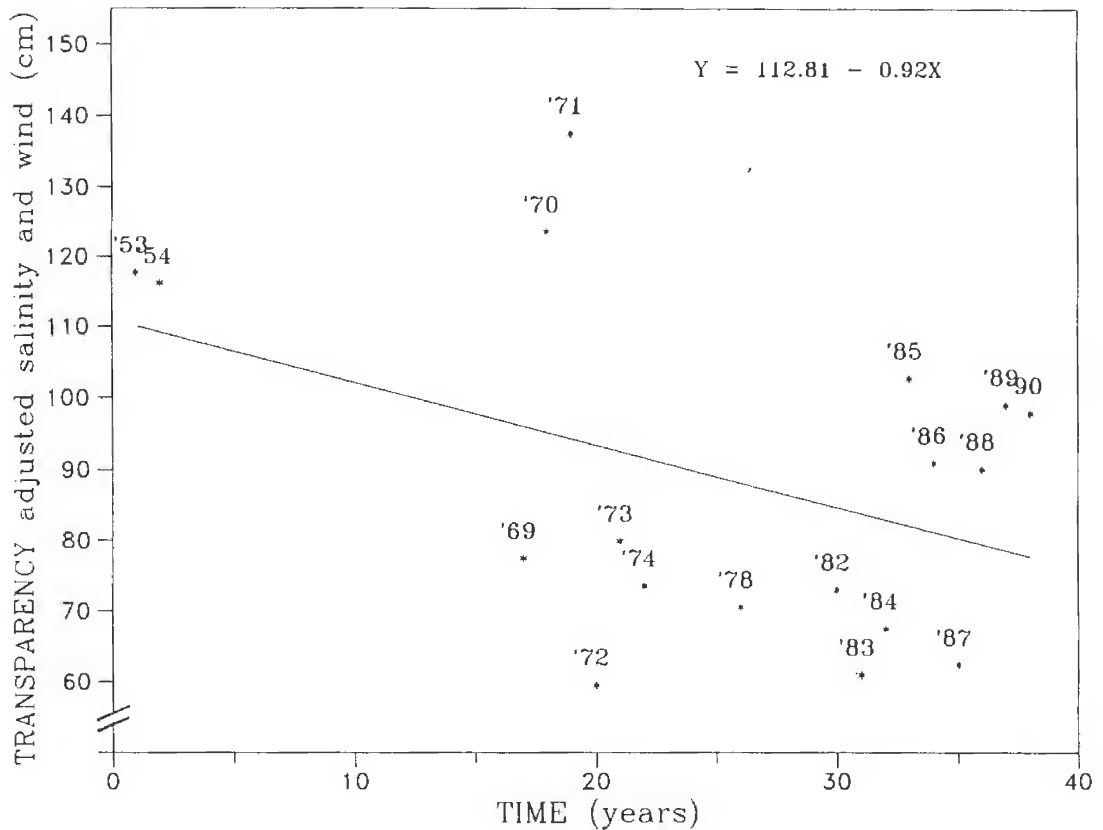


Figure 11. Annual mean Secchi disk transparency from 1953 through 1990 adjusted for salinity and wind speed.

Secchi disk transparency values for those years in which continuous data were available from January through June; (3) The derived data set contained all of the original data on Secchi disk transparency in addition to estimated values for those months in which data was not available. In each case, when the seasonal bias was removed from the original data, it no longer supported the conclusion of a statistically significant change in Secchi disk transparency from 1953 to 1990; $p > 0.4$.

Results of this study do not support the long-term increase in turbidity of almost 50% reported by Stone (1980). Although urban runoff is known to produce short-

term increases in water turbidity near outfall canals (Stern and Stern, 1969), data examined in this study do not indicate a long-term, lake-wide increase.

ACKNOWLEDGMENTS

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NAMALYCASTIS ABIUMA (MÜLLER IN GRUBE) 1871, AN ABERRANT NEREIDID POLYCHAETE OF A GEORGIA SALT MARSH AREA AND ITS FAUNAL ASSOCIATIONS

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ABSTRACT The morphology of the aberrant nereidid *Namalycastis abiuma*, Namanereidinae is described on the basis of material collected 1971-72 and 1976 in the brackish water drainage ditch system of Sapelo Island, Georgia, USA. The systematics of the species is briefly reviewed. The habitat and ecological conditions under which the species lives in these brackish ditches are described.

At various times, *N. abiuma* lives out of water under the bark of trunks and branches of fallen trees. Decaying wood is ingested. It is suggested that future studies should concentrate on the reproductive biology of the widely-spread, mainly tropical populations of what may prove to be not one, but several species of *Namalycastis*. A list of the invertebrate fauna associated with *N. abiuma* is included with notes on these associates.

INTRODUCTION

Namalycastis abiuma (Namanereidinae, Nereidae) was described by Müller in Grube, 1871 as *Paranereis abiuma*. Eleven closely-related species subsequently were described under the generic name *Lycastis*. These species occur in fresh water to brackish or almost fully marine habitats (Wesenberg-Lund, 1958). All species were referred to by the new generic name *Namalycastis* by Hartman (1959), with the comment that all "are believed to refer either to a single species resembling the type, or to closely related, and generically identical forms" (p. 163). Hartman's diagnosis, based on material from Florida, has been generally accepted (Foster, 1972; Gardiner, 1976; Gardiner and Wilson, 1977; Heard, 1975, 1982). Heard (1982) synonymized *Lycastopsis tecolulensis* Rioja, 1946, *L. pontica* Jakubova, 1930, and *L. hummelincki* Augener, 1933, all from North Carolina, Georgia, Florida and Louisiana with *N. abiuma*. *N. abiuma* was reported from Australia by Russell (1962) and *N. cf. abiuma* by Hutchings and Glasby (1985). Although it may seem difficult to accept that Hartman rightly synonymized 11 species of *Abiuma*, considering the diversity of their habitats, it must be noted that only a limited number of systematic characteristics are available, e.g., a pharynx without paragnaths or papillae, reduced parapodia, etc. Therefore, until a more thorough revision of the many forms is available, it seems reasonable to accept Hartman's inclusion of them as members of *Abiuma*.

In this paper, the systematics of *N. abiuma* were briefly reviewed and some morphological details were described based on material from brackish water in Georgia. An

attempt has been made to characterize ecological conditions under which the species occurred, its mode of life, and its faunal associates.

MATERIALS AND METHODS

Site Description

The study area encompassed shallow drainage ditches on Sapelo Island connected to the sea only during periods of extreme high water. A series of ditches, dwindling into pools at low water with different salinity conditions, were chosen for sampling. Populations of *N. abiuma* were found at only two of 10 stations surveyed: Station 1, the main station regularly examined during 1971-72, and Station 10, a supplementary station visited only a few times in 1976 (Figure 1). Station 1 (Figure 2), situated one mile north of the Settlement, was a roadside ditch about 4 m wide and varying in depth from a few cm during dry periods to more than 0.5 m at spring tides. The bottom layer was soft, fine, blackish mud with some smell of hydrogen sulphide. Fallen tree trunks and decaying branches from the surrounding pine forest were piled up in part of the ditch system. Rickards (1968) gave a short description of this study area.

Except for a small patch of *Ruppia maritima* L., present only in 1976, the ditches had no submerged vascular plants. The surface of the mud was covered with a dense brownish layer of diatoms during periods with clear direct sunshine. Tufts of perennial glasswort (*Salicornia virginiana* L.)

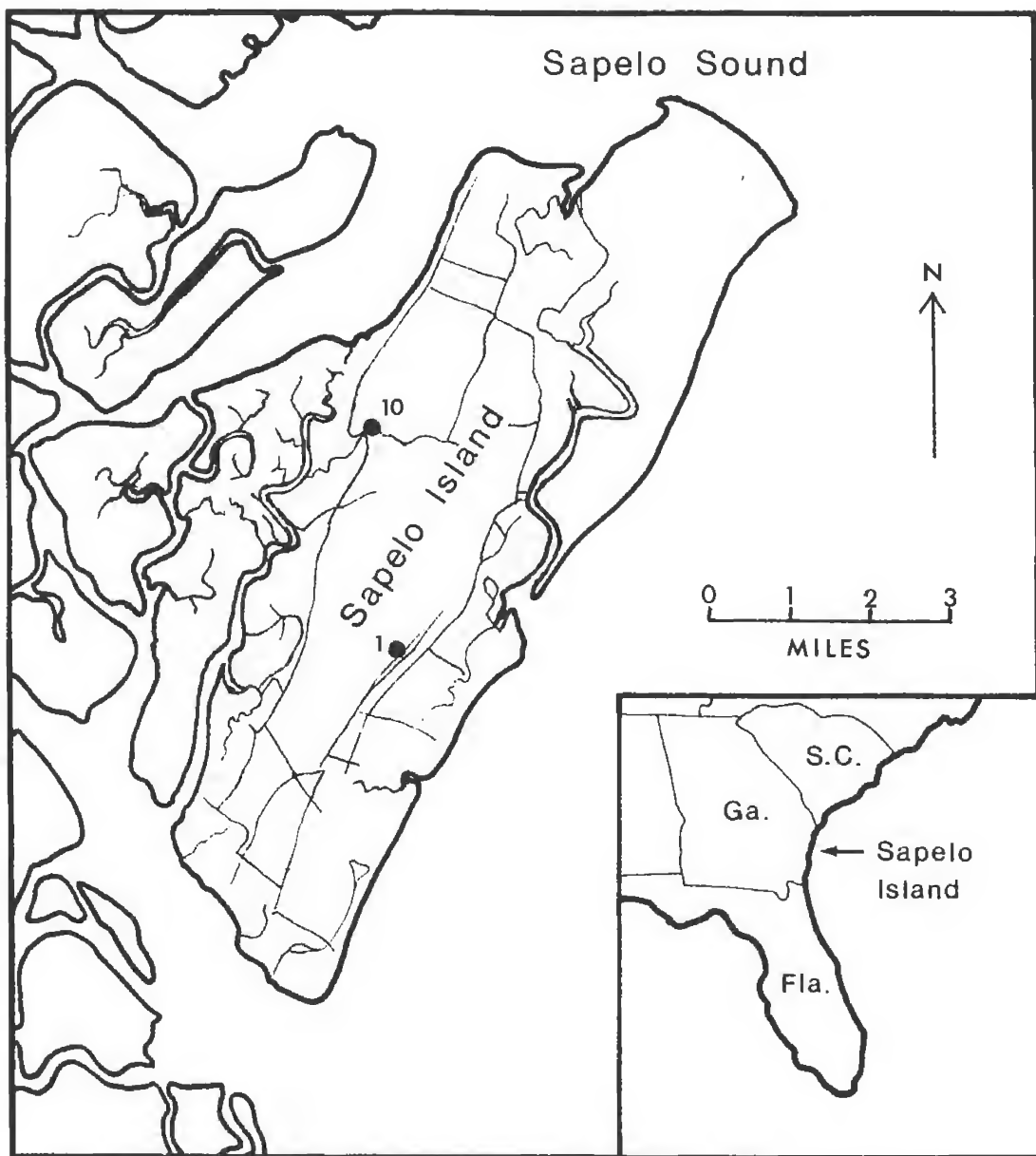


Figure 1. Sapelo Island, Georgia, with tidal creeks, ditches and pools. Numbers indicate sampling stations.

were found on the bank of the ditch near the saltgrass cover (*Distichlis spicata* (L.) Greene). Low bushes of marsh elder (*Iva frutescens* L.) formed a transitional border near the forest in the *Distichlis* marsh clearings. Saltmarsh grass

(*Spartina alterniflora* Lois.) occurred in some places along the bank edges and often extended across the ditch to form thresholds that often impeded the upstream flow of sea water.



Figure 2. Photograph showing part of Station 1, a roadside ditch with *Spartina* grass along the banks (to the right, opposite the road). Behind the *Distichlis* grass cover bushes of marsh elder (*Iva frutescens*) are bordering the pine tree forest in the background (April 23, 1971).

Station 10 was a ditch located between steep bluffs which ran parallel to the road between the King Savannah clearing and the Bell Marsh near the High Point road. It was surrounded by dense forest. The steep banks of the ditch reached 2 m above the bottom. The bottom sediment was virtually clean sand with plant remnants and scattered *Spartina*. The banks were topped with a dense growth of marsh elder. The ditch was nearly dry during sampling periods. Direct access to sea water gave this ditch a regular tidal cycle.

Salinity

Salinity was measured with a T/C refractometer (American Optical Corp.). Salinity at Station 1 varied greatly according to the irregular rainfall pattern. During most of 1971-72, the salinity varied from ca. 10‰ to ca. 30‰, but drought combined with high air temperature and intense sunlight raised the salinity to 56 in June 1971. However, heavy rains in June and July reduced that salinity to 4‰ within a few days.

In contrast, 1976 was an extraordinarily dry year. At Station 1 from March 13 to April 16, total precipitation was ca. 27 mm (seasonal norm 182 mm). The ditch became almost dry in April, and the remaining stagnant pools became hypersaline at ca. 80‰. But on April 12, a single intrusion of sea water at a spring tide raised the water level to 40 cm and lowered the salinity to that of normal sea water. It appears that fluctuations in salinity over a range of ca. 20‰ are a usual occurrence in spring and early summer. The 80‰ event represents an extreme that the fauna of the ditches must endure occasionally, possibly by retreating to the underbark refuge out of water. This may present other stresses, such as high temperature and the risk of desiccation.

Temperature

Temperatures were measured from April to August 1971 with a mercury thermometer. From late September 1971 to early February 1972, water temperature was measured each week with a permanently submersed maximum-

minimum mercury thermometer that showed the temperature range during the past seven days. From March 14-27, the temperature range was measured continuously with a Grant Miniature Temperature Recorder with six channels registering the air temperature, water surface temperature in the middle of the ditch, water surface temperature near the bank, temperature near the bottom, temperature 1 cm in the mud bottom and temperature 15 cm deep in the mud with a water level ranging from 0.5 to about 40 cm (Figure 3). Rainfall records for 1971-72 were obtained from the meteorological station of the University of Georgia Marine Institute. During the 1976 sampling, precipitation was checked by a rain gauge placed on the ground close to Station 1. Water level was measured daily against a measuring rod placed in the ditch (Figure 2).

The temperature range at Station 1 was very large, both seasonally and daily, influenced by changes in air temperature and solar radiation. After a period of rhythmic fluctuations in April and May 1971 varying between 22°C and 32°C, the hottest period in the 1971-72 study came in June and lasted through September, with a peak of nearly 37°C in June. A more precise estimate of the temperature range was achieved with the introduction of regular maximum-minimum temperature recording of the ditch system water from September 26 through the rest of the research period. A minimum of 0°C was recorded in January 1972.

From March 14-27, 1976, the water level of the pool in Station 1 varied between 10 and 27 mm and the temperature ranged between 12°C and nearly 31°C, never attaining the low level of the air due to the strong solar radiation

(Figure 3). What may be more important is the fact that the narrower temperature range in the mud (15°C to 26.5° at 1 cm depth; 20° to 30°C at 15 cm) might enable some mobile animals to survive under extreme environmental conditions by burrowing into the mud. However, such an escape may subject them to anoxic conditions, and *N. abiuma* was never actually found in the mud in this study.

NAMALYCASTIS ABIUMA

Descriptive Notes

Mature specimens measure about 50 to 100 mm in length, with up to 170 setigers. Body with two, not distinctly separable sections. Anterior third to half rather slender and cylindrical with relatively few segments, rest of body becoming flattened posteriorly, with segments increasingly shorter. Living animal translucent, unpigmented. Color determined by contents of red blood, increasing in intensity posteriorly. Dorsal surface somewhat glossy in reflected light. Epidermis of each segment with fine transverse wrinkles (Figure 4). Prostomium trapezoidal, anteriorly incised, with short median groove. Two small conical antennae and two conspicuous, broad palps with distinct palpostyles; the palps are rhythmically extended when the worm crawls. Posterior part of prostomium broader with two pairs of eyes, black in reflected light, the outer eye on each side larger (Figure 4). Four pairs of tentacular cirri, the hindmost pair longest. First segment achaeous. Pharynx strongly built, without paragnaths or papil-

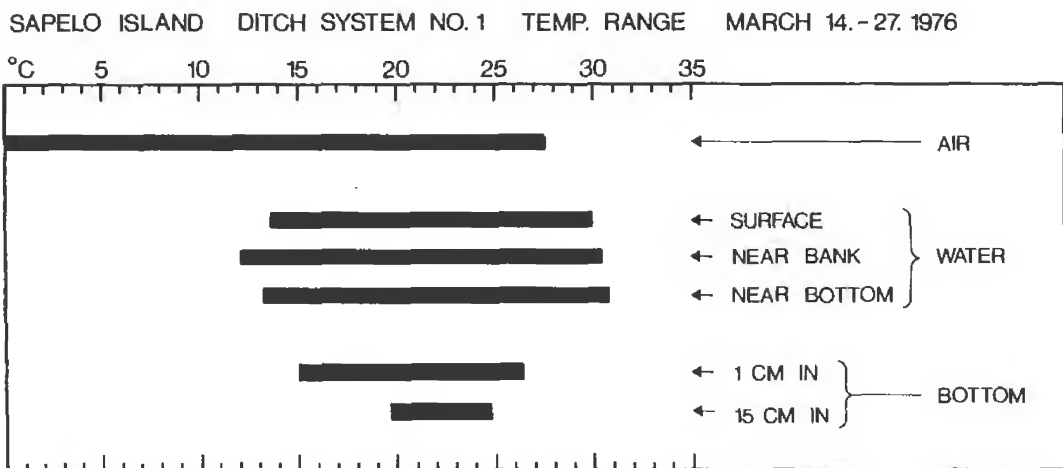


Figure 3. Temperature range in air and ditch at Station 1, Sapelo Island, Georgia, March 14-27, 1976. Measured continuously during this period with a six-channel temperature recorder. All measurements, except "near bank", made over and in the central and deepest part of the ditch. The "bank" channel was at the surface near the water edge. Depth during recording from 10 to 27 cm, falling to 9 cm.

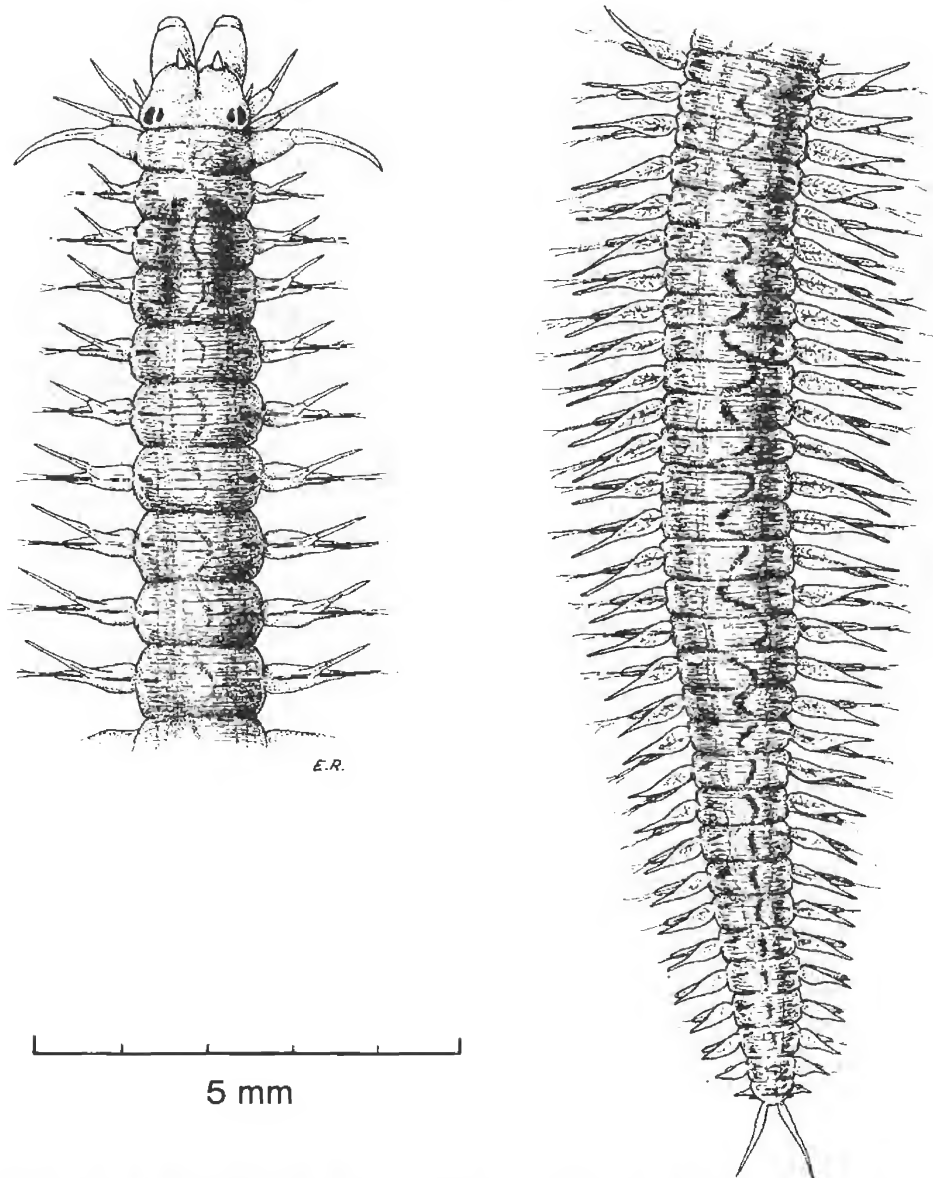


Figure 4. *Namalycastis abiuma* (Müller in Grube, 1871). Adult specimen from Station 1, Sapelo Island, Georgia, November 1971, showing anterior and posterior ends of the body. Drawn from life with the aid of a camera lucida.

lae, with two dark brown, strong chitinous jaws (Figure 5). Jaws concave, almost spoon-shaped, in living animals visible through the first 2-3 setigers; median edge of each jaw with a row of teeth. The terminal tooth, somewhat separated from the row of teeth, slightly larger than the rest. Each jaw with fine growth rings. Parapodia sub-biramous with noto- and neuropodial aciculae,

dark brown or almost black. Notopodia normally reduced, without setae except for an occasional, slender heterogomph spiniger. Dorsal cirri anteriorly slender and small, conically shaped; posteriorly long, flattened leaflike in structure with constricted terminal tips and a very rich supply of fine capillary vessels. Ventral cirri small throughout.

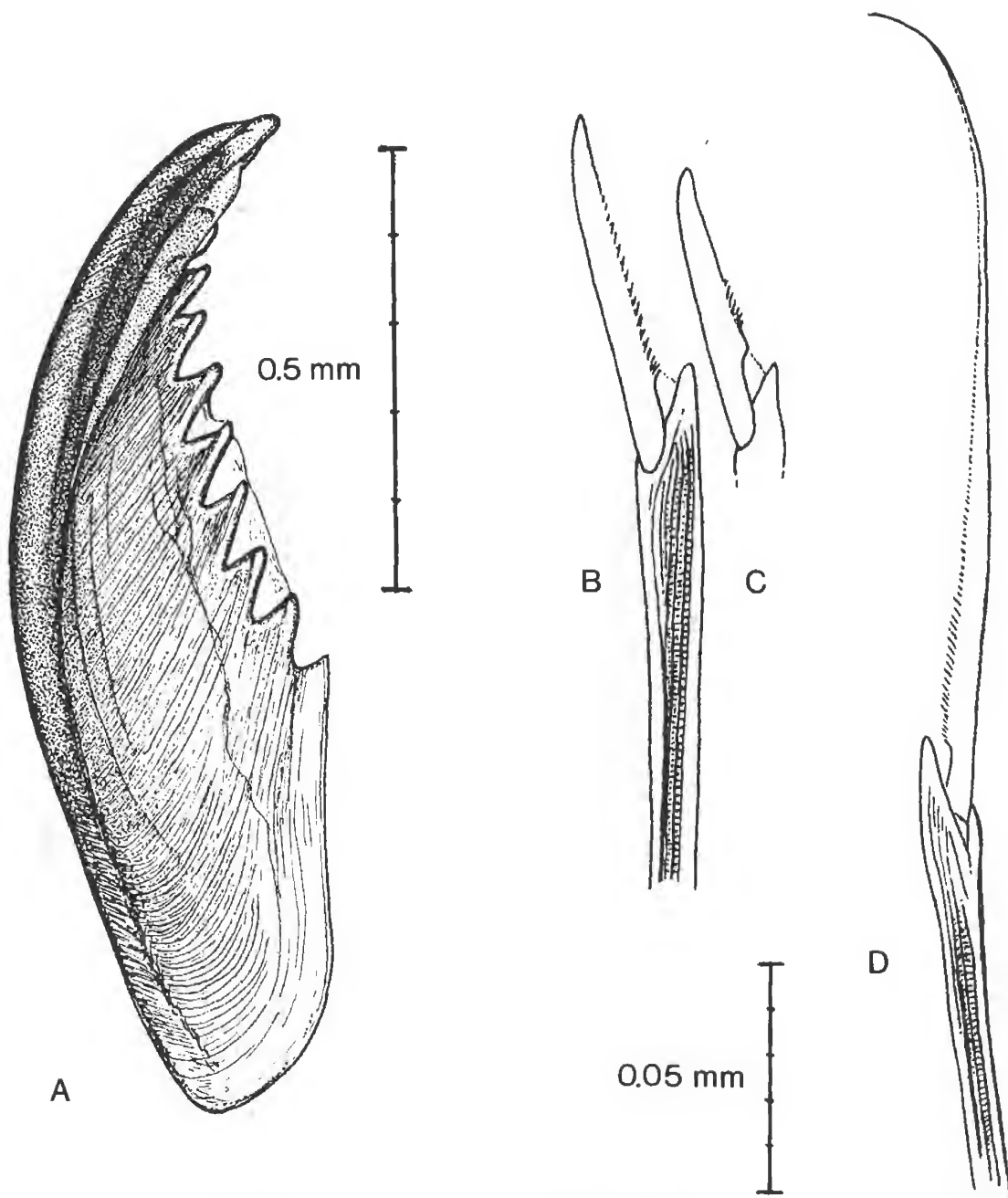


Figure 5. *Namalycastis abiuma*. Sapelo Island, Georgia. A) Right jaw seen from the ventral, concave side, 11 teeth, one hidden by the terminal tooth. From a 70 mm long specimen. B-C) Neuropodial heterogomph falcigers, showing variation in dentation of the blades. D) Neuropodial heterogomph spiniger; all from 24th setiger.

Mature individuals with 11 to 21 neurosetae in each fascicle; neurosetae of two types: heterogomph falcigers, numbering maximally 9 per fascicle, and heterogomph spinigers with up to 12 per fascicle (Figure 5). Highest number of each setal type per fascicle found in the first third of the body, declining in number posteriorly. Any bundle of setae with dominance of spinigers. Heterogomph falcigers with blades finely denticulated, sometimes at base only and of varying lengths (Figure 5B-C). Heterogomph spinigers with long, finely denticulate blade tapering into hairlike tip. Both falcigers and spinigers with dense structure of transverse lamellae in core of shaft, most distinct in falcigers.

The dorsal, longitudinal vessel has a slightly meandering course in the first few segments, with meanders increasing in amplitude considerably toward the posterior end (Figure 4) (normally straight in nereidids (Lindroth, 1938; Nicoll, 1954)). The capillary supply is extraordinarily rich in the dorsal part of the posterior segments and in the leaflike, flattened dorsal cirri. Fresh dissection and sectioning of adult worms from Sapelo Island has shown that each segment in the worm body has pulsating "gill hearts" composed of two contractile chambers (Figure 6). Feuerborn (1931) has described such hearts in *Namalycastis ranauensis*; otherwise, they are rarely reported in nereidid worms (Nicoll, 1954).

Biological Observations

N. abiurna was recorded from early November 1971 to January 1972 and February-March 1976, with greatest abundance in fall and winter. It was found under the bark

of rotten pine trunks and branches in or above the ditch water. Heard (1982) also noted the presence of *N. abiurna* in Mississippi living under nearly semi-terrestrial conditions.

Except during the period from November 1971 to March 1972, *N. abiurna* was not observed anywhere in the ditches, not even the mud bottom. All specimens recorded had guts filled with wood pieces (Figures 7-8) and the inside of the surrounding bark had distinct marks made by the jaws of the worms. *N. abiurna* lives freely under the bark and has no permanent tubes; the worms crawled away quickly when bark was removed from the branches. In some cases, they could live semi-terrestrially in the wood pieces since parts of the branches protruded freely in the atmosphere. The worm proved to be a very fast swimmer when released from the wood. It seems likely that the worms under the bark were foraging, perhaps prior to reproduction. All worms taken in November were large, mature individuals with small eggs in their segments. The spring specimens were smaller and without sexual products.

Earlier accounts (Heard, 1982) have established that *N. abiurna* is able to survive under very extreme environmental conditions. At very low oxygen tensions, the posterior end of the worm, with its foliaceous cirri rich in capillary vessels, is seen extended from holes in the bark and waving freely in the surrounding water (aquarium observations, Sapelo Island). This was also observed by Feuerborn (1931, p. 650) for *Lycastis* (*Namalycastis*) *ranauensis* and personally for *Nereis succinea* from Sapelo Island (see below).

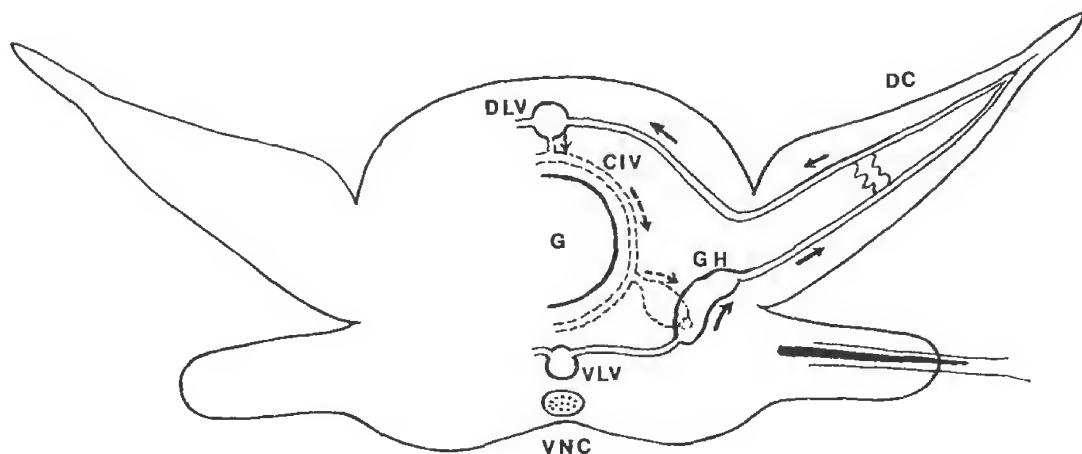


Figure 6. *Namalycastis abiurna* (Müller in Grube, 1971). Schematic diagram of the vascular system showing the main segmental vessels. CIV, circum-intestinal vessel; DC, dorsal cirrus; DLV, dorsal longitudinal vessel; G, gut; GH, gill heart; VLV, ventral longitudinal vessel; VNC, ventral nerve cord.

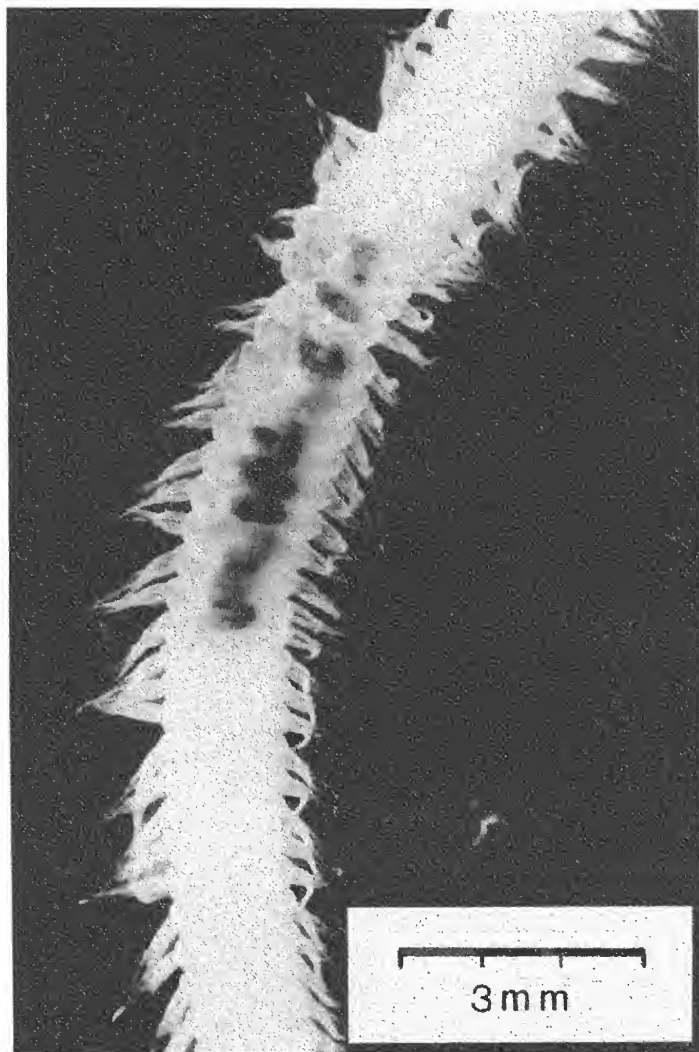
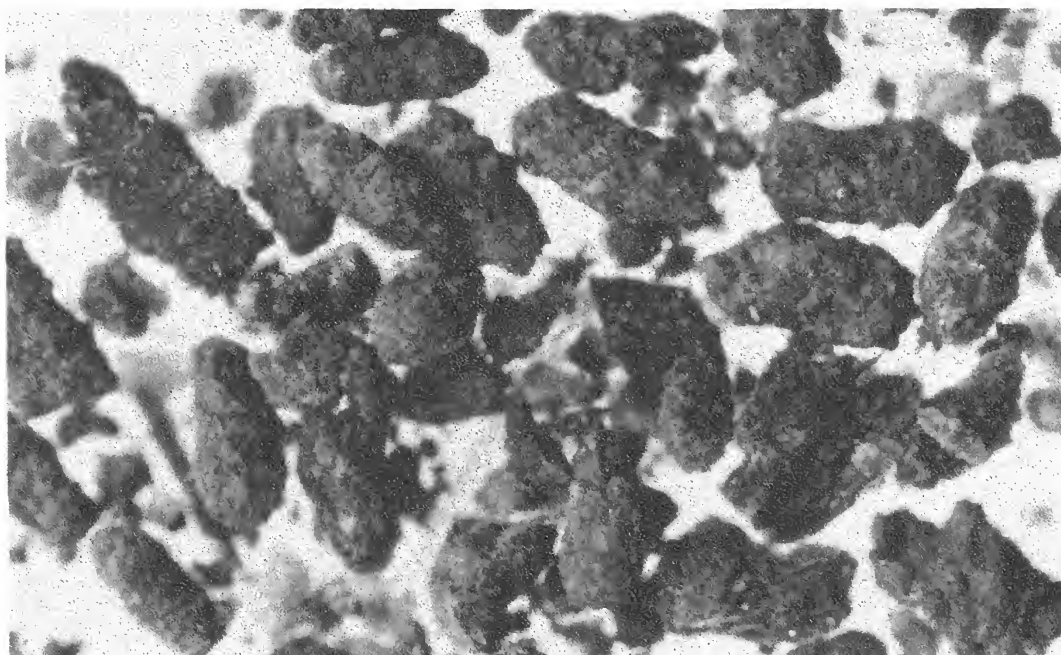


Figure 7. *Namalycastis abiuma*. Sapelo Island, Georgia, November 1971, Station 1. Middle section of adult, preserved specimen with wood and bark pieces in the gut.

Little is known about the reproduction and development of *N. abiuma*. Only small egg cells were observed in the coelom in the material from Sapelo Island (November 1971), and developmental details were not obtained. The only more extensive breeding information for a member of the *Namalycastis* group is given by Feuerborn (1931, Figure 10) for *Lycastis* (*Namalycastis*) *ranauensis* from Java. He

found the species to be hermaphroditic with relatively small eggs, 125-135 μ in diameter and laid in a common jelly mass. After about four days the larvae, about 300 μ long, hatched into what Feuerborn described and figured as a ciliated nectochaete stage with three setigers and clearly biramous parapodia. The subsequent fate of the larvae was not described. Because of its freshwater habitat, it seems



3 mm

Figure 8. *Namalycastis abiuna*. Sapelo Island, Georgia, November 1971. Fecal pellets from adult specimen with remnants of bark and wood particles.

very unlikely that *N. abiuna* has a free-swimming pelagic stage. Only Heard (1982), who kept individuals of *N. abiuna* in aquaria, mentioned large eggs with direct development as the most likely form of propagation of the species, but gave no further information. Otherwise, there are virtually no details of the propagation of other *Namalycastis* species.

Faunal Associations

The survey below comprises benthic species living associated with *Namalycastis abiuna* on or under the bark of dead and windfallen branches mostly of pine trees, predominantly the loblolly pine, *Pinus taeda* L., lying in the brackish water of Sapelo Island ditches.

▲ indicates presence under bark and in wood

△ indicates presence on surface of branches

POLYCHAETA

▲ *Nereis (Neanthes) succinea* (Frey and Leuckart, 1847).

Very common at all examined places, both in 1971-72 and 1976. Often large specimens; maximum length of living animal 170 mm. It burrows under bark and seems to feed on decaying wood. The animals were surrounded by brownish excrement masses, undoubtedly originating from devoured wood remnants. Individuals from March 24, 1976 were almost sexually ripe and in the heteronereid stage. Under low oxygen tensions combined with high water temperatures, the posterior end of the worm, with its many ligules rich in capillary vessels, was seen extended and waving freely in the water (laboratory observations). In case of extreme low oxygen conditions, the species may leave the water and live partly amphibious under the bark of branches exposed to the air.

▲ *Stenonireis martini* Wesenberg-Lund, 1958

This tiny aberrant nereid species is another remarkable member of the decaying wood biotope of the tidal ditches of Sapelo Island. It was found both during 1971-72 and in March-April 1976, frequently in groups of up to six individuals at a time and always in grooves under the bark. All specimens were taken only in the spring in different parts of the ditches. Living individuals measured 7-12 mm. One ripe male specimen was collected on April 16, 1976. The morphology and systematic characters of the examined specimens agree with the description given by Pettibone, 1971.

The species occurs mainly in tropical-subtropical America. Since first described in 1958 by Wesenberg-Lund from St. Martin in the West Indies, it has been recorded from the eastern and northwestern parts of the Gulf of Mexico and from North Carolina. It is known from open water and tidal ponds with great fluctuations in salinity (St. Martin) and penetrates into environments characterized by widely fluctuating conditions: warm mineral springs (Florida), salt marshes (Texas and Mississippi), *Spartina* marsh (North Carolina), and on silt and muddy substrate with little or no oxygen (Hartman, 1958; Pettibone, 1971; Williams *et al.*, 1976; Gardiner and Wilson, 1977; Heard, 1982).

▲ *Polydora ligni* Webster, 1879

Three smaller specimens in mud tubes under pine tree bark.

▲ *Hobsonia florida* (Hartman, 1951)

A single, ca. 12 mm long specimen in mud tube under bark, Bell Marsh ditch system (Station 10), March 28, 1976, salinity 8. The systematic characters agree with the description by Banse, 1979.

CRUSTACEA

△ *Balanus eburneus* Gould, 1841

Fairly common, especially on the undersides of the branches; maximum basic diameter 25 mm. Newly settled individuals present on March 28, 1976 in the Bell Marsh ditch system.

△ *Balanus improvisus* Darwin, 1854

Common, predominantly on the sheltered sides of the branches. On November 11, 1979, numerous small, newly-settled specimens present, less than 1 mm across. On April 23, 1976, pelagic larvae in abundance at Station 1.

▲ *Hargeria rapax* (Harger, 1879) = *Leptochelia rapax* Harger, 1879

1 female with eggs, 3.5 mm long, under bark, Bell Marsh ditch system, March 28, 1976.

▲ *Cyathura polita* Stimpson, 1855

Single specimen under bark, Bell Marsh ditch system, March 28, 1976.

△▲ *Cassidinidea ovalis* (Say, 1818) = *C. lunifrons* (Richardson, 1900)

In quantity under bark. From both Station 1 and the Bell Marsh ditch system, where a few individuals were observed crawling on branches. Females with eggs, March 28, 1976.

▲ *Sphaeroma terebrans* Bate, 1866 = *S. desiructor* Richardson, 1897

In quantity under bark and in shipworm-bored branches in all ditches examined.

△▲ *Gammarus daiberi* Bousfield, 1969

Adult specimens numerous on and under the bark of pine branches, also in wood bored by shipworms, salinity 8‰. Females with eggs, March 28, 1976.

This American endemic species is rather newly described by Bousfield (1969). It has a restricted distribution in estuarine systems from the Delaware and Chesapeake Bay regions south to South Carolina. According to Bousfield, the most dense populations are at salinities of 1-5‰ and in mid-water to near bottom depths. It may be found at 15‰ salinity, then largely pelagic; and development within one year. Oviparous females occur from March to October. Its occurrence on Sapelo Island seems to be the most southern on record.

△▲ *Melita nitida* Smith, 1873

Adult specimens (both sexes) common under pine tree bark at Station 1, November 1971 and January 1972. In March 1976 on and in rotten ranches.

△ *Uhlorchestia uhleri* (Shoemaker, 1936)

Often in numbers, crawling on submerged parts of branches close to the water surface.

▲ *Panopeus herbsti* H. Milne-Edwards, 1834

Two young females, carapace width 12 and 13 mm, in empty shipworm tubes.

▲ *Eurytium limosum* (Say, 1818)

Two males, carapace width 5.5 mm, under bark, Station 1, January 20, 1972.

▲ *Sesarma reticulatum* (Say, 1817)

One female, carapace width 7 mm, under bark, Station 1, January 20, 1972.

▲ *Sesarma cinereum* (Bosc, 1801 or 1802)

Common under bark, carapace width 2.5 to 16 mm, Station 1, 1971-72 and 1976.

INSECTA

▲ Chironomid larvae, blood-red species, a few in mud tubes under bark.

▲ Odonata, unidentified species, a single larva under bark; November 11, 1971 at 20‰ salinity.

MOLLUSCA

△▲ *Melampus bidentatus* Say, 1822

A few small specimens under bark in water; also observed crawling on submerged parts of the branches.

- ▲ *Geukensia demissa* (Dillwyn, 1817) = *Modiolus demissus* (Dillwyn, 1817)
A few byssally-attached specimens under bark, length about 15 mm.
- △ *Crassostrea virginica* (Gmelin, 1791)
Common on branch surfaces, maximum size 80 mm, many dead shells.
- ▲ *Bankia gouldi* Bartsch, 1908
Fairly common, often in small and thin branch pieces.
- ▲ *Teredo bartschi* Clapp, 1923
Fairly common, often in small and thin branch pieces.

ENTOPROCTA

- △ *Barentsia* sp.
Not very common, on surface of bark in various ditch systems.

ECTOPROCTA

Living colonies of the following species were found in abundance on the surfaces of branches, attached barnacles and oysters.

- △ *Membranipora tenuis* Desor, 1848
- △ *Electra monostachys* (Busk, 1854)
- △ *Conopeum tenuissimum* (Canu, 1928)
- △ *Bowerbankia gracilis* O'Donoghue, 1926
- △ *Alcyonidium polyomm* (Hassall, 1841)
- △ *Victorella* sp.

ASCIDIACEA

- △ *Molgula manhattensis* (De Kay, 1843)
Present, but uncommon, as large specimens on the outer surface of branch pieces.

ACTINIARIA

- ▲ Even one tiny unidentified flesh-colored sea anemone was taken under loose pine bark below sea water.

DISCUSSION

In considering the taxonomic status of *Abioma*, even generally established systematic characters must be used with care. For example, the position of the eyes of *N. abioma* may be different according to the condition of the preserved material. In the Sapelo Island material, living worms had the eyes in a transverse row (Figure 4), while they were behind each other in preserved and somewhat shrunken specimens.

An aid in species separation within the genus *Namalycastis* may be offered by possible differences in modes of propagation and development. Hartman (1959, p. 163) mentions one form of the type species (*Paranereis* (*Namalycastis*) *abioma* Müller in Grube, 1871) from Brazil, which was described as having small eggs and separated sexes, with no mention of further development. Another form (*N. ranauensis*) with small eggs,

hermaphroditism, and an ectochaete stage (perhaps pelagic) was described by Feuerborn (1931). Both forms were from freshwater. The results of Heard (1982) indicate large eggs and direct development for what he considers to be the type species *N. abioma* from brackish water. Still rather incomplete, these descriptions, apparently with the same external characters, may suggest three different species at any rate. Further studies on the breeding biology of this aberrant group may provide a clue to the speciation problems within the genus *Namalycastis*.

The ingestion of decaying and rotten wood seems to be unknown for nereidids and perhaps for polychaete worms as a whole (Fauchald and Jumars, 1979). Not only *Namalycastis abioma* has this peculiar feeding pattern, but *Nereis* (*Neanthes*) *succinea* also consumes decaying wood, as shown in this study. It seems reasonable to assume that the fraction of importance for the two species is the microorganisms of the wood.

Off the German coast, *N. succinea* is a deposit-feeder and detritus-feeder (Goerke, 1971). *N. abioma* may also be a deposit-feeder in other parts of its range of distribution. Thus their diets may vary greatly and both may be characterized as omnivores. However, as pointed out by Fauchald and Jumars (1979, p. 255), "...a widely dispersed species feeds on a limited range of materials, indicating that, while the species as a whole may be omnivorous, each population may be functionally specialized."

The fauna associated with *N. abioma* in or on fallen branches in the ditch water comprises 34 benthic species. Apart from the two freshwater insects, the remaining are brackish-water, estuarine or euryhaline marine species. There is a clear dominance of crustaceans with 13 species, followed by five polychaetes, five molluscs, and six ectopods (bryozoans).

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The material collected is deposited in the Zoological Museum, Copenhagen.

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A New Species and Two Known Species of Free-Living Marine Nematodes (Nematoda: Monoposthiidae) from Northwest Florida, U.S.A.

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A NEW SPECIES AND TWO KNOWN SPECIES OF FREE-LIVING MARINE NEMATODES (NEMATODA: MONOPOSTHIIDAE) FROM NORTHWEST FLORIDA, U.S.A.

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ABSTRACT Two known free-living marine nematodes, *Monoposthioides mayri* Wieser and Hopper, 1967 and *Monoposthia hexalata* Chitwood, 1936 are redescribed from sediments in St. Andrew Bay and Lake Powell, Bay County, Florida, U.S.A. One new species of free-living marine nematode, *Monoposthia baxteri* n. sp., is described from nonvegetated sediments in St. Andrew Bay, Bay County, Florida. *M. baxteri* n. sp. differs from the other members of the genus in the shape of the gubernaculum which is more similar to that of the species of *Monoposthioides* than that of *Monoposthia*.

INTRODUCTION

According to Lorenzen (1981), the family Monoposthiidae Filipjev, 1934 contains the genera *Monoposthia* de Man, 1889; *Monoposthioides* Hopper, 1963; *Nudora* Cobb, 1920; and *Rhinema* Cobb, 1920. The Monoposthiidae are characterized by the presence of a cuticle with strong transverse striations forming annuli, and a number of longitudinal cuticular ridges that appear as V-shaped markings. Vanreusel and Vincx (1989) referred to these structures as costae. The amphids are circular and are situated on the second annulus. The buccal cavity has a well-developed dorsal tooth and may have one or more ventral teeth or denticles.

Specimens of two of the four genera of the Monoposthiidae were collected from estuarine waters in northwest Florida. The two known and one new species of free-living marine nematodes in the genera *Monoposthioides* Hopper, 1963 and *Monoposthia* de Man, 1889 redescribed and described, respectively, herein were collected from subtidal sediments in St. Andrew Bay and Lake Powell, Bay County, Florida. The sediments from the collection sites in St. Andrew Bay and Lake Powell were nonvegetated fine sand and silt.

MATERIALS AND METHODS

Sediment samples were obtained with a cylindrical core sampler to a depth of 4-10 cm, depending on the site. Nematodes were extracted from the sediment by repeated decantation. The suspended material from four washings was allowed to settle for 15-20 minutes, and the supernatant water was decanted. Nematodes were removed alive from

the settled material and fixed in hot alcohol-formalin-acetic acid or hot 4% formalin in seawater for 24 hours. Specimens were dehydrated in glycerine by gradually bringing them to 70% ethyl alcohol and glycerine (9:1) and allowing the alcohol to evaporate. Specimens were mounted in anhydrous glycerine on Cobb slides. Specimens were deposited in the Florida Nematode Collection, University of Florida, Gainesville, Florida (UFNC).

All measurements are given in μm unless otherwise stated, and the mean is followed by the range in parentheses. Abbreviations: l = length of body in mm. w = width at midbody. hd = head diameter at level of first annulus. cs = length of cephalic sensilla. ad = width of amphid. aa = anterior end to anterior margin of amphid. bc = length of buccal cavity. nr = anterior end to nerve ring. es = length of esophagus. t = length of tail. cw = width at cloaca. aw = width at anus. av = anterior to vulva. a, b, c, V = demanian ratios.

TAXONOMIC ACCOUNT

(After Lorenzen, 1981)

Chromadorida Filipjev, 1929

Monoposthiidae Filipjev, 1934

Monoposthioides Hopper, 1963

Monoposthioides mayri Wieser and Hopper, 1967

Figures 1-12

Description: Body relatively short, broad. Cuticle coarsely annulated; annuli originate immediately posterior to cephalic sensilla; first and second annuli larger than succeeding annuli. Annuli are complete lateral to cloaca.

Costae in 12 longitudinal rows; fully developed V-shaped costae originate between annuli 10 and 20 from anterior end [(38.5(30-56) in males; 60(50-77) in females]. Apex of costae directed posteriorly then reverse to anterior direction 234.7(218-256) from anterior end in males, 319.7(301-346) in females. In males, lateral, subventral, and ventral rows of costae terminate at level of cloacal opening; remaining rows terminate immediately posterior to cloacal opening. In females, subventral and ventral rows of costae terminate at level of vulva; remaining rows terminate posterior to anal opening. Head with circle of six, small, inner labial sensilla immediately adjacent to oral opening. Circle of six papilliform outer labial sensilla and four long, setiform cephalic sensilla present. Long cervical, somatic, and caudal sensilla present as subdorsal and subventral rows on each lateral surface. Amphid circular, situated on second annulus. Buccal cavity with cyathiform anterior chamber with circle of 12 small, flap-like structures. Anterior chamber of buccal cavity elongate with cuticularized, parallel walls. Esophagus with asymmetrical peribuccal expansion; dorsal side larger. Large, muscular, bipartite, posterior, esophageal bulb present with moderately cuticularized lumen. Excretory pore not observed. Tail conical, terminal one third without annuli; spinneret and caudal glands present.

Males (n = 6): l = 1.15(1.01-1.28). w = 40.1(38-43). hd = 16(14-17). cs = 22(21-24). ad = 2.8(2.5-3.0). aa = 13.8(13-16). bc = 23.7(19-27). nr = 68(61-75). es = 144.2(125-155). t = 99.8(93-106). cw = 31(29-34). a = 28.6(26.6-31.6). b = 7.98(7.23-8.53). c = 12.1(10.6-15.3). Male reproductive system diorchic. Large, non-striated, precloacal process present. Spicules absent. Single, heavily cuticularized gubernaculum present, 46.6(45-48) arc, 51(48-56) chord long, arcuate with proximal flange, dorsally directed process of flange longer than ventrally directed process.

Females (n = 3): l = 1.15(1.11-1.20). w = 50(48-51). hd = 16.7(16-18). cs = 19.7(19-21). ad = 4.0(3.0-5.0). aa = 13.3(13-14). bc = 25.3(22-27). nr = 78(72-82). es = 157(144-173). t = 94(90-101). aw = 25.7(24-27). av = 979(949-1020). a = 22.9(21.8-23.5). b = 7.33(6.94-7.85). c = 12.2(11.9-12.6). V = 85.3%(85-86). Female reproductive system monodelphic, prodelphic, ovary reflexed. Vulva with cuticular flap.

Specimens: Males, UFNC A157, A158, A159; females, UFNC A160.

Locality: St. Andrew Bay, Bay County, Florida (30°08'33"N, 85°42'43"W). Nonvegetated fine sand and silt.

Remarks: The specimens described above are considered to be *Monoposthioides mayri* based on the shape and size of the gubernaculum of the male, the enlarged second annulus, and the shape and size of the amphid. In the original description of *M. mayri*, the buccal cavity was

described as having a single, large, dorsal tooth and small subventral projections. These projections are part of three circles of small denticles that are not easily observed. The presence of inner labial sensilla was not mentioned in the original description or figured on the drawings. The male specimens described above differ from the original description of the male in that the costae reverse at a greater distance from the anteriorend [234.7(218-256) vs. 140] and the cephalic sensilla are longer [22(21-24) vs. 17]. The female specimens described above differ from the original description of the females of *M. mayri* in that the "V" value is less than that of *M. mayri* (85-86% vs. 90-92%) and the costae reverse somewhat more posteriorly than in *M. mayri* (301-346 vs. 240-250 from the anterior end).

Monoposthia de Man, 1889

Monoposthia baxteri n. sp.

Figures 13-21

Description: Body relatively short, broad. Cuticle coarsely annulated; second annulus with anterior bulge at location of amphid. Annuli incomplete subventrally and ventrally in cloacal region of male. Costae in eight longitudinal rows; dorsal, subdorsal, subventral, and ventral rows originate on third annulus, lateral rows originate on annulus 13-15. Apex of costae directed posteriorly, reverse direction on annulus 83-88 from anterior end (posterior to esophageal bulb) in males; costae did not reverse in single female examined. In males, laterals, subventrals, and ventral rows of costae terminate at about level of cloacal opening; subdorsals and dorsal rows of costae terminate posterior to cloacal opening. In female, laterals, subventrals, and ventral rows of costae terminate at vulva; subdorsals and dorsal rows terminate immediately posterior to anal opening. Head with circle of six, setiform, inner labial sensilla immediately adjacent to oral opening. Circle of six, setiform, outer labial sensilla and circle of four, long, setiform cephalic sensilla present. Amphid circular, situated on second annulus. Long cervical, somatic, and caudal setiform sensilla present as subventral and subdorsal rows on each lateral surface. Buccal cavity with anterior cyathiform chamber with 12 flap-like structures. Large, heavily cuticularized, dorsal tooth and three circles of denticles present. Circles of denticles broken subdorsally and dorsally. Posterior chamber of buccal cavity elongate with cuticularized, parallel walls. Peribuccal region of esophagus expanded, asymmetrical; dorsal side larger. Large, muscular, bipartite, esophageal bulb with weakly cuticularized lumen present posteriorly. Excretory pore not observed. Tail conical, terminal one third without annuli; spinneret and caudal glands present.

Males (n = 2): l = 1.05(1.04-1.06). w = 56(54-58). hd = 22(22-22). cs = 26.5(26-27). ad = 3.0(3.0-3.0). aa =

10(10-10). $bc = 30.5(29-32)$. $nr = 81(80-82)$. $es = 157.5(155-160)$. $cw = 36(35-37)$. $t = 55(54-56)$. $a = 18.8(18.3-19.3)$. $b = 6.67(6.50-6.84)$. $c = 11.6(11.4-11.8)$. Reproductive system diorchic. Non-striated, preloacal process present. Spicules absent. Gubernaculum large, 55(54-56) arc, 60(59-61) chord long, arcuate, thorn-shaped with inner cuticularization. Distal end expanded with ventral process longer than dorsal process. Small teeth present on ventral surface of proximal tip of gubernaculum in paratype male, not observed in holotype male. Cuticle inflated in one place on midventral surface anterior to cloaca.

Female ($n = 1$): $l = 1.02$. $w = 51$. $hd = 18$. $cs = 21$. $ad = 4$. $aa = 11$. $bc = 29$. $nr = 77$. $es = 144$. $aw = 27$. $t = 83$. $av = 914$. $a = 20.0$. $b = 7.08$. $c = 12.3$. $V = 90\%$. Reproductive system monodelphic, prodelphic, ovary reflexed. Vulva with cuticular flap.

Specimens: Male, holotype, UFNC A166; male, paratype, UFNC A168; female, allotype, UFNC A167.

Locality: St. Andrew Bay, Bay County, Florida (30°08'33"N, 85°42'43"W). Nonvegetated fine sand and silt.

Remarks: Hopper (1963) erected the genus *Monoposthioides* to accommodate the species *Monoposthioides anonoposthia* Hopper, 1963 that was collected from the northern coast of the Gulf of Mexico. The genus *Monoposthioides* can be differentiated from the genera *Nudora*, *Rhinema* and *Monoposthia* in that the costae originate about midlevel of esophagus in *Monoposthioides* rather than on the second or third annulus as in the other three genera. In addition, *Monoposthioides* differs from *Nudora* and *Rhinema* in the absence of spicules.

Monoposthioides is most similar to the genus *Monoposthia* in that the spicules are absent and a single well-developed gubernaculum is present. Hopper (1963) differentiated *Monoposthioides* from *Monoposthia* on the basis that the costae originate much more posteriorly in *Monoposthioides*, the gubernaculum of the male in *Monoposthioides* is relatively larger and more arcuate with a large, ventrally directed process proximally and long spine distally, and the reproductive system of the male in *Monoposthioides* is diorchic. Wieser and Hopper (1967) emended the diagnosis of *Monoposthioides* to include the species *Monoposthioides mayri* Wieser and Hopper, 1967. In *M. mayri*, the long, distal spine of the gubernaculum is absent and the dorsal process of the proximal end of the gubernaculum is longer than the ventral process.

The diorchic male reproductive system cannot be used as a differentiating character of *Monoposthioides*, because diorchic males of known species of *Monoposthia* have been described by Kito (1981) and Vanreusel and Vincx (1989). Platt and Warwick (1988) use the diorchic condition of the male reproductive system as a character of the family

Monoposthiidae. Therefore, the genus *Monoposthioides* currently differs from *Monoposthia* in that the costae originate more posteriorly, and the gubernaculum is relatively larger and more arcuate in *Monoposthioides*.

Monoposthia baxteri n. sp. has characters of both *Monoposthia* and *Monoposthioides*. It is similar to *Monoposthia* in that the costae begin on the third annulus and to *Monoposthioides* in that the gubernaculum is relatively large, arcuate, and the proximal end has a large ventral process. *Monoposthia baxteri* n. sp. is placed in the genus *Monoposthia* based on the origin of the costae on the third annulus.

Monoposthia baxteri n. sp. is differentiated from all other members of the genus *Monoposthia* on the basis of the shape of the gubernaculum. It is the only species with a large, arcuate gubernaculum with an expanded proximal end with the ventral process longer than the dorsal process.

Etymology: *Monoposthia baxteri* n. sp. is named for Dr. George Baxter, Professor Emeritus, University of Wyoming, in recognition of his work and teaching in aquatic biology.

Monoposthia hexalata Chitwood, 1936

Figures 22-29

Description: Body relatively short, broad. Cuticle coarsely annululated. Second annulus not significantly larger than succeeding annuli but with an anterior bulge where the amphid is located. Annuli complete laterally and ventrally in cloacal region of male, but these annuli are not as distinct as the surrounding annuli. Costae in six longitudinal rows; originate on third annulus. Apex of costae directed posteriorly, reverse direction immediately posterior to esophageal bulb in males, immediately anterior to vulva in females. In males, subventral and ventral rows of costae terminate immediately anterior to cloaca; remaining rows terminate posterior to cloaca. In females, subventral and ventral rows of costae terminate immediately anterior to vulva; remaining rows terminate at or near last annulus on tail. Head with circle of six setiform inner labial sensilla immediately adjacent to oral opening. Circle of six setiform outer labial sensilla and four long, setiform, cephalic sensilla present. Amphid circular, situated on second annulus. Cervical, somatic, and caudal setiform sensilla present as subdorsal and subventral rows on each lateral surface. Buccal cavity with anterior cyathiform chamber with 12 flap-like structures. Anterior chamber of buccal cavity with single, large, heavily cuticularized dorsal tooth and pair of small, subventral, denticles; circles of denticles not observed. Posterior chamber of buccal cavity elongate with cuticularized, parallel walls. Peribuccal region of esophagus expanded, asymmetrical; dorsal side larger. Large, muscular, bipartite, esophageal bulb with weakly

cuticularized lumen present posteriorly. Excretory pore not observed. Tail conical; terminal one third without annuli; spinneret and caudal glands present.

Males ($n=5$): $l=0.963(0.831-1.06)$. $w=48.4(43-53)$. $hd=18.6(17-19)$. $cs=24.8(22-26)$. $ad=3.1(3.0-3.2)$. $aa=7.4(7-10)$. $bc=25.6(22-29)$. $nr=77.6(67-86)$. $es=148.8(133-165)$. $cw=36.6(24-43)$. $t=92.2(80-99)$. $a=20.0(15.7-22.1)$. $b=6.47(6.11-6.82)$. $c=10.6(8.4-13.0)$. Reproductive system diorchic. Spicules absent. Gubernaculum claw-shaped $39.2(34-43)$ arc, $42.4(36-47)$ chord long, with proximal expansion with dorsally directed process, internal cuticularization, and arcuate distal part. Single large, subventral, papilliform, precloacal sensillum present on each lateral surface. Cuticle inflated midventrally in two places anterior to cloaca, particularly evident when tail is bent ventrally.

Female ($n=1$): $l=0.945$. $w=67$. $hd=22$. $cs=19$. $ad=5$. $aa=11$. $bc=29$. $nr=80$. $es=174$. $aw=26$. $t=82$. $av=788$. $a=14.1$. $b=5.43$. $c=11.5$. $V=83\%$. Reproductive system monodelphic, prodelphic, ovary reflexed. Vulva with cuticularized flap.

Specimens: Males, UFNC A161, A162, A163, A164; one female, UFNC A165.

Locality: St. Andrew Bay, Bay County, Florida ($30^{\circ}08'33''N$, $85^{\circ}42'43''W$) and Lake Powell, Bay County, Florida ($30^{\circ}16'45''N$, $85^{\circ}58'50''W$). Nonvegetated fine sand and silt.

Remarks: The specimens described above agree closely with the description and drawings of *M. hexalata* provided in the original description given by Chitwood (1936). They differ from the original description in that there is a pair of precloacal papillae in the males that were not mentioned or figured in the original description. Chitwood (1936) describes and figures (Figure 2E) a circle of inner labial sensilla immediately adjacent to the oral opening but did not describe the circle of flap-like structures.

Key to the Species of the Genus *Monoposthia* De Man, 1889 Based on Males

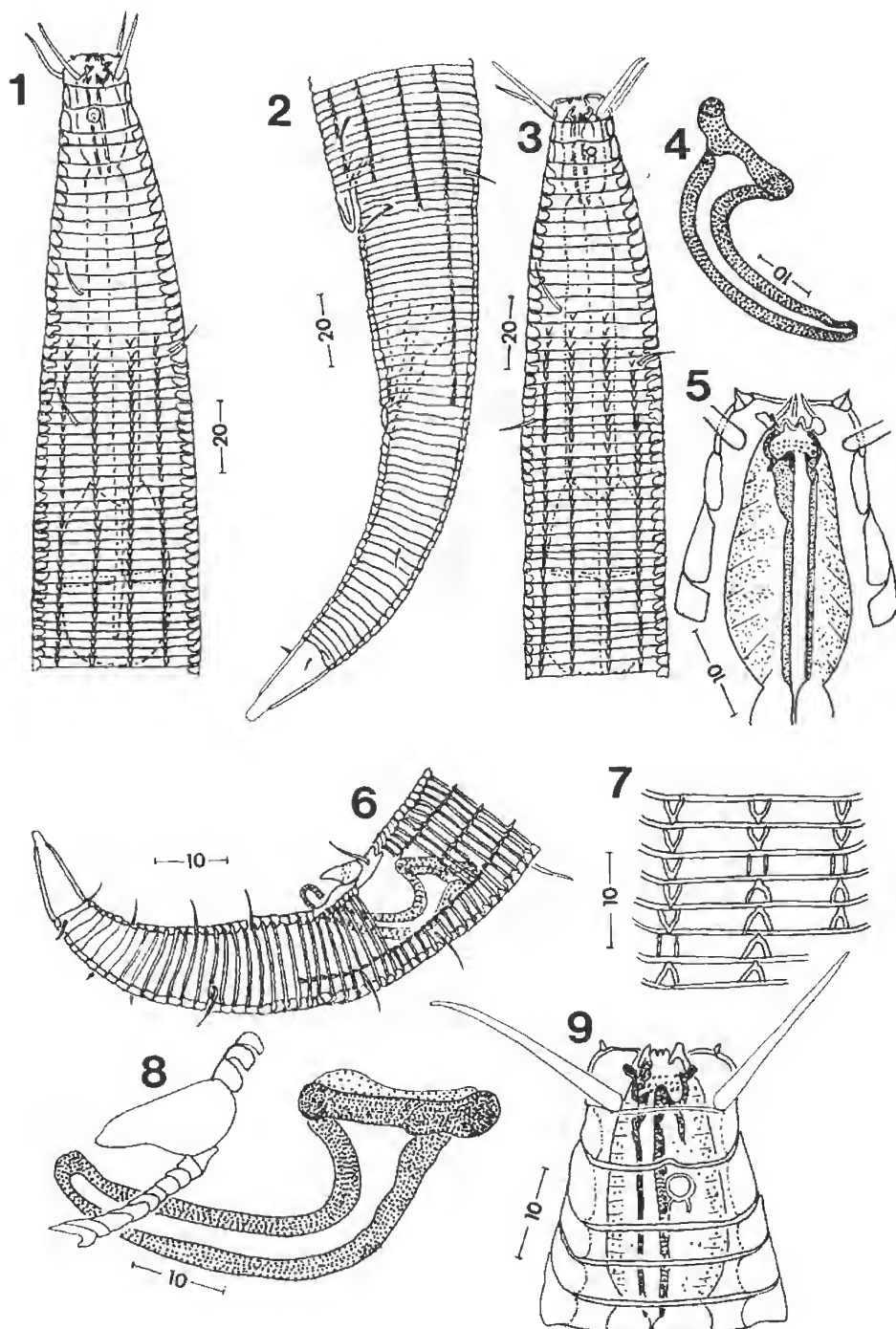
Wieser and Hopper (1967) presented a key to the species of the genus *Monoposthia* in which the second annulus was distinctly larger than succeeding annuli. The key included *Monoposthia thorakista* Schulz, 1935.

Gerlach and Riemann (1974) listed the species of *Monoposthia*, transferred *M. thorakista* to the genus *Nudora* Cobb, 1920, and listed the following species of the genus *Monoposthia* as valid: *M. arctica* Allgen, 1954; *M. costata* (Bastian, 1865) De Man, 1889; *M. desmodoroides* Allgen, 1959; *M. duodecimalata* Chitwood, 1936; *M. falklandiae* Allgen, 1959; *M. grahami* Allgen, 1959; *M. hexalata* Chitwood, 1936; *M. latianulata* Platonova, 1971; *M. mielcki* Steiner, 1916; *M. mirabilis* Schulz, 1932; and *M. paramediterranea* Allgen, 1959. The genus also includes *Monoposthia octalata* Gal'tsova, 1976 from the White Sea.

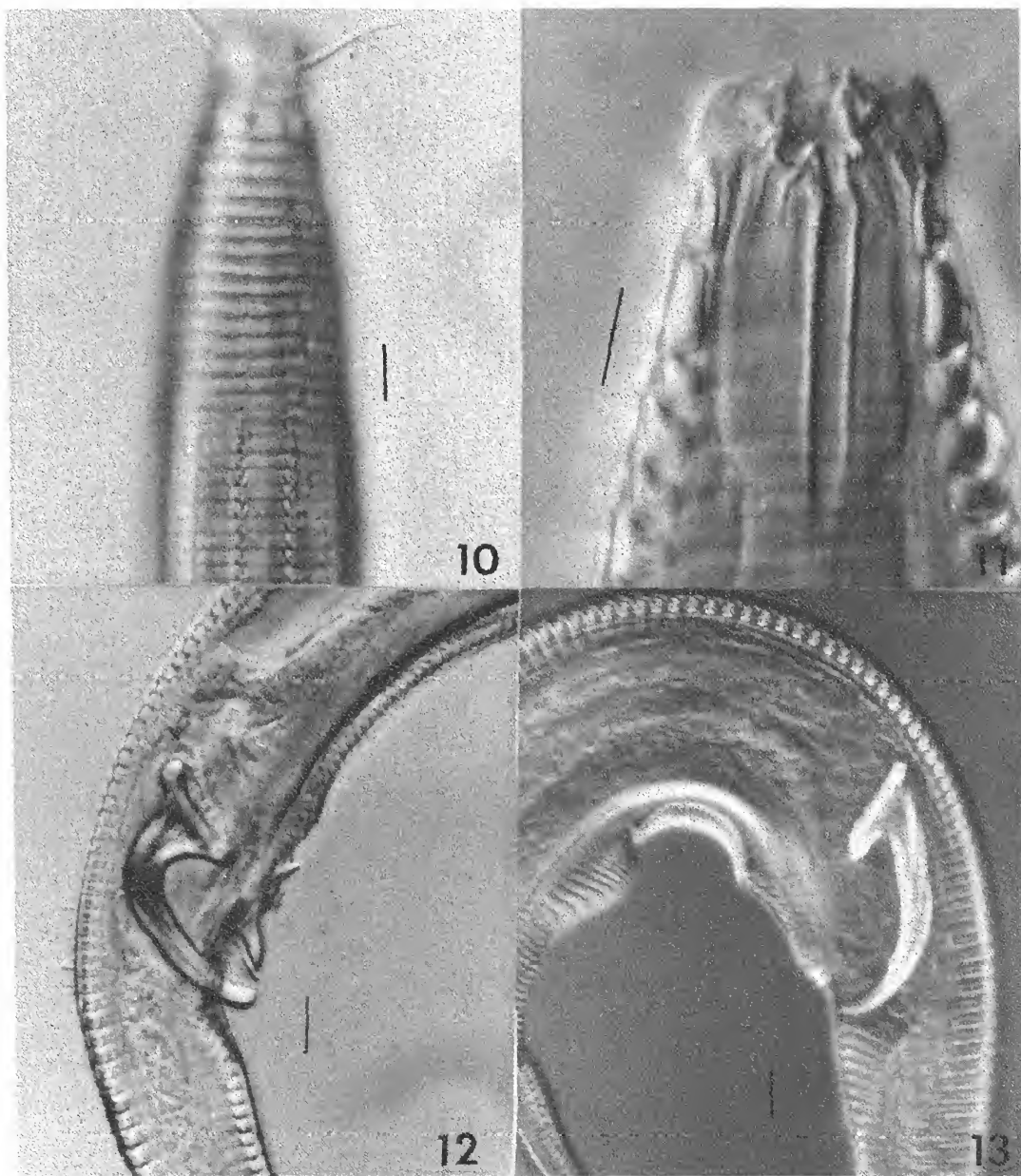
Examination of the original descriptions of the above listed species revealed that the following species of *Monoposthia* should be considered *species inquirenda* because only the female is known for some of the species or, if males are known, probably belong in the genus *Nudora* because of the presence of spicules and a gubernaculum: *M. arctica* Allgen, 1954; *M. desmodoroides* Allgen, 1959; *M. falklandiae* Allgen, 1959; *M. grahami* Allgen, 1959; *M. paramediterranea* Allgen, 1959.

In the following key to the species of the genus *Monoposthia*, the part of the key involving those species with an enlarged second annulus is modified from that given by Wieser and Hopper (1967) to exclude *M. thorakista*.

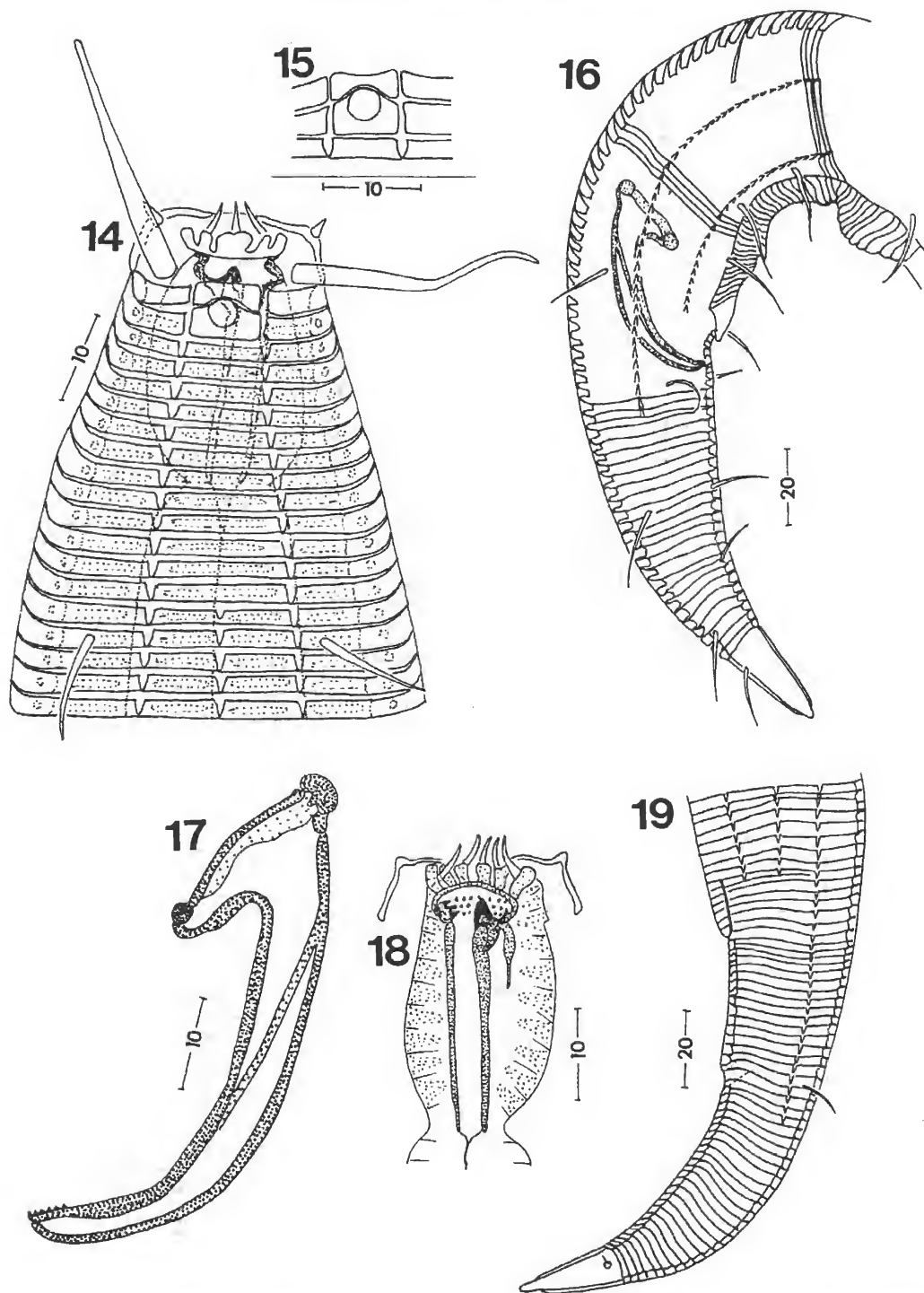
1. Second annulus distinctly larger than succeeding annuli 2
Second annulus not distinctly larger than succeeding annuli 4
- 2(1). Cuticle with 12 longitudinal rows of costae *Monoposthia duodecimalata* Chitwood, 1936
Cuticle with 6 longitudinal rows of costae 3
- 3(2). Cephalic sensilla less than 0.5 head diameter long; amphids about 0.33 of corresponding body diameter wide *Monoposthia mielcki* Steiner, 1916
Cephalic sensilla about 1.0 head diameter long; amphids about 0.17 of corresponding body diameter wide *Monoposthia mirabilis* Schulz, 1932
- 4(1). Cephalic sensilla absent *Monoposthia latianulata* Platonova, 1971
Cephalic sensilla present 5
- 5(4). Cuticle with 10-20 longitudinal rows of costae *Monoposthia costata* (Bastian, 1865)
Cuticle with 6 or 8 longitudinal rows of costae 6
- 6(5). Cuticle with 6 longitudinal rows of costae *Monoposthia hexalata* Chitwood, 1936
Cuticle with 8 longitudinal rows of costae 7
- 7(6). Cephalic sensilla less than 1.0 head diameter long; gubernaculum $35.1\text{ }\mu\text{m}$ long, broad, almost straight with curved distal part and dorsally directed proximal part *Monoposthia octalata* Gal'tsova, 1976
Cephalic sensilla more than 1.0 head diameter long; gubernaculum $54-56\text{ }\mu\text{m}$ long, narrow, arcuate distal part and broad proximal part with ventrally directed process longer than dorsally directed process *Monoposthia baxteri* n. sp.



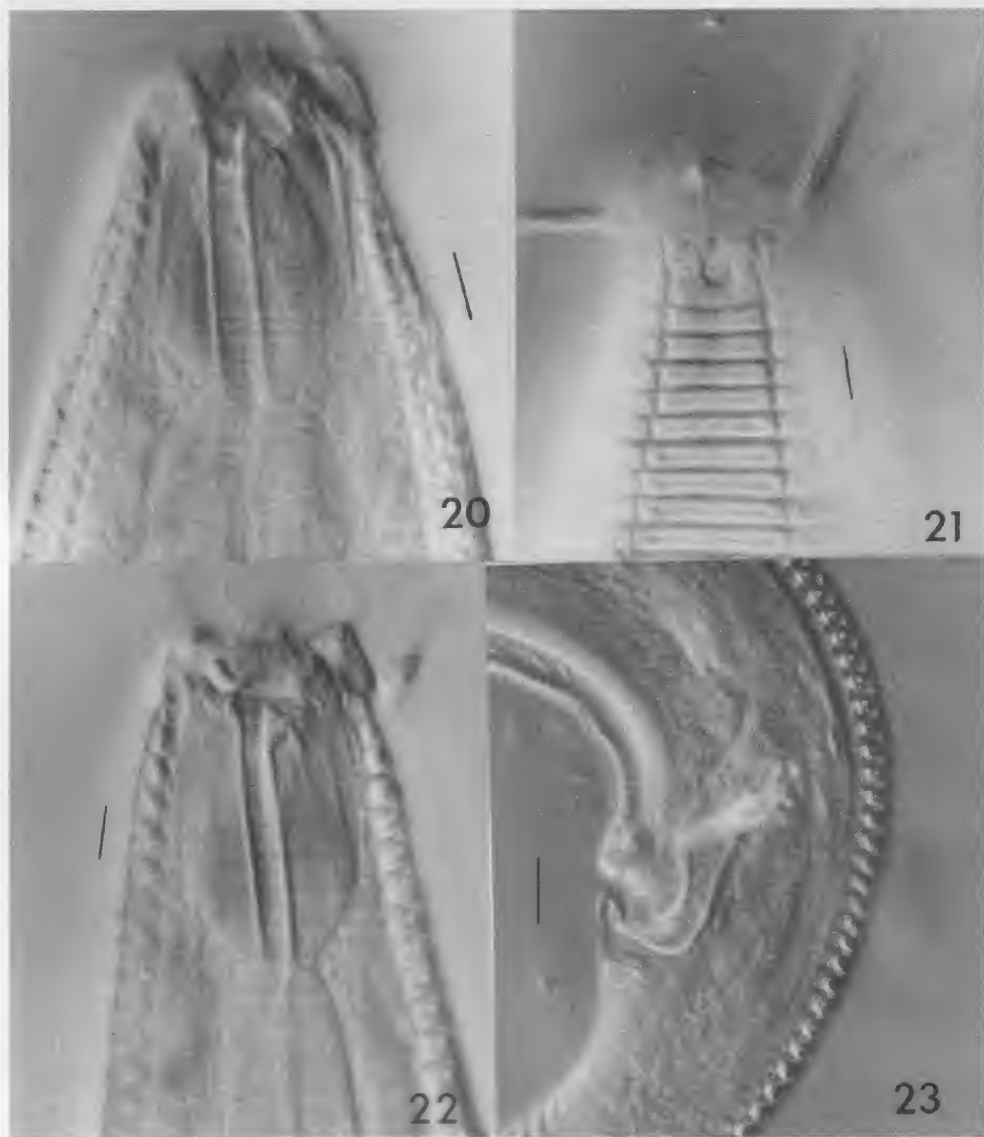
Figures 1-9. *Monoposthioides mayri* Wieser & Hopper, 1967. Fig. 1. Female, anterior end. Fig. 2. Female, posterior end. Fig. 3. Male, anterior end. Fig. 4. Male, gubernaculum. Fig. 5. Male, buccal cavity. Fig. 6. Male, posterior end. Fig. 7. Male, cuticle in region of reversal of costae. Fig. 8. Male, gubernaculum. Fig. 9. Male head. All scale bar values are given in μm .



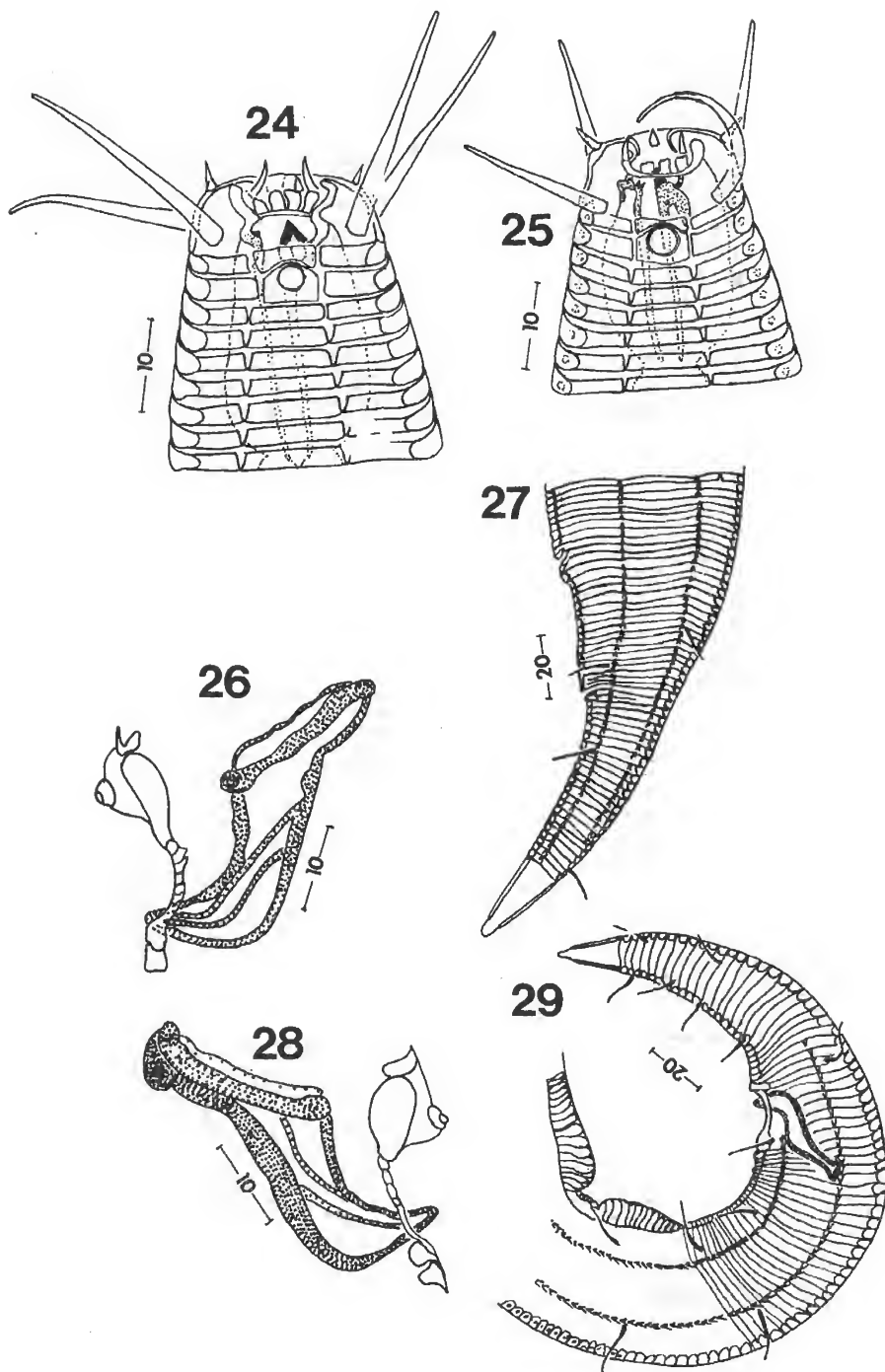
Figures 10-13. *Monoposthioides mayri*. Fig. 10. Male, anterior end with origin of costae, scale bar = 10 m. Fig. 11. Male, buccal cavity, scale bar = 5 m. Fig. 12. Male, gubernaculum, scale bar = 10 m. Fig. 13. *Monoposthia baxteri* n. sp. Fig. 13. Male, gubernaculum, scale bar = 10 μ m.



Figures 14-19. *Monoposthia baxteri* n. sp. Fig. 14. Male, head. Fig. 15. Male, first three annuli. Fig. 16. Male, posterior end. Fig. 17. Male, gubernaculum. Fig. 18. Male buccal cavity. Fig. 19. Female, posterior end. All scale bar values are given in µm.



Figures 20-21. *Monoposthia baxteri* n. sp. Fig. 20. Male, buccal cavity, scale bar = 5 m. Fig. 21. Male, amphid, scale bar = 5 m. Figures 22-23. *Monoposthia hexalata* Chitwood, 1934. Fig. 22. Male, buccal cavity, scale bar = 5 m. Fig. 23. Male, gubernaculum, scale bar = 10 μ m.



Figures 24-29. *Monoposthia hexalata* Chitwood, 1936. Fig. 24. Male, head. Fig. 25. Female, head. Fig. 26. Male, gubernaculum and cloacal region. Fig. 27. Female, posterior end left. Fig. 28. Male gubernaculum and cloacal region. Fig. 29. Male, posterior end. All scale bar values in μm .

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Behavioral Ecology of Two Teal Species (Blue-Winged Teal, *Anas discors*, and Green-Winged Teal, *Anas crecca*) Overwintering in Marshes of Coastal Louisiana, USA

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BEHAVIORAL ECOLOGY OF TWO TEAL SPECIES (BLUE-WINGED TEAL, *ANAS DISCORS*, AND GREEN-WINGED TEAL, *ANAS CRECCA*) OVERWINTERING IN MARSHES OF COASTAL LOUISIANA, USA

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ABSTRACT Feeding and other dominant activities of Blue-winged Teal (BWT; *Anas discors*) and Green-winged Teal (GWT; *Anas crecca*) were compared from October 1987 to March 1988 in southwestern Louisiana, USA. Three observation towers were constructed near similar intermediate marsh habitats in areas where BWT and GWT concentrated for feeding. These observation towers allowed activities of the two species to be compared throughout the nonbreeding season. Although BWT and GWT often fed together, time spent in various activities differed. Feeding was the most frequent activity of both BWT (64.5%) and GWT (55.3%), but BWT spent more time feeding ($P < 0.01$) and alert ($P < 0.05$), but spent less ($P < 0.01$) time resting than GWT. Within each species there were differences in activity budgets among daily time blocks and among months, but few differences among the three habitats studied. Temperature and light intensity were correlated with resting (+), feeding (-), locomotion (-), and preening (+). Daily and monthly activity budgets of BWT and GWT were similar, as were ingested foods, suggesting that these two species used the study areas primarily for foraging, and left the areas for other activities. Predation and diminished resources during late winter may have affected activities of BWT and GWT as well.

INTRODUCTION

Blue-winged Teal (BWT; *Anas discors*) and Green-winged Teal (GWT; *Anas crecca*) are two of the most common waterfowl species in North America. Most BWT migrate to Central and South America during the nonbreeding season, but some remain along the U.S. Gulf Coast and overwinter with GWT and other waterfowl. This is the first comparative study of the two species.

Most previous studies of BWT concerned breeding or postbreeding feeding ecology (reviewed by DuBow, 1985); however, several studies were conducted recently on activities of nonbreeding GWT (Tamisier, 1976; Baldassarre and Bolen, 1984; Quinlan and Baldassarre, 1984; Euliss and Harris, 1987; Rave, 1987; Rave and Baldassarre, 1989; Gaston, 1992). The purpose of this study was to compare activities of BWT and GWT concurrently. This allowed us to compare the two species under identical conditions, which is not possible unless the birds are observed simultaneously. Specifically, our goals were to (1) determine whether BWT and GWT required similar foraging times in habitats used primarily for feeding (intermediate marshes), since previous studies indicated that BWT and GWT food preferences differed during winter (Bellrose, 1980); (2) determine whether predators affected BWT and GWT foraging and habitat selection, as suggested in studies of other waterfowl species in these coastal Louisiana marshes (Gaston and Nasci, 1989); and (3) determine whether the role of their habitat changed as food resources diminished during winter.

MATERIALS AND METHODS

Blue-winged Teal were observed at the 30,756 ha Rockefeller State Wildlife Refuge (SWR) in southwestern Louisiana (see Paulus, 1982). The area is closed to hunting, public access is limited, and much of it is impounded to control water levels.

Birds were observed from blinds (4 m high) located on levees adjacent to three intermediate marsh impoundments. Intermediate marshes are generally lower salinity (annual salinity range: 0-5 ppt.) than brackish marshes, and are transition zones between salt marshes and fresh marshes. The dominant vegetation of intermediate marshes in the study area was wiregrass (*Spartina patens*), cattail (*Typha* spp.), bulrush (*Scirpus californicus*), common reed (*Phragmites australis*), and bearded sprangletop (*Leptochloa fascicularis*). Levees surrounding the study areas supported dense stands of common reed, which allowed access to the towers with minimal disturbance to waterfowl. The three areas were described by Gaston and Nasci (1989). The areas were generally similar, but varied in water level ranges and pond sizes. Observation was planned in these similar areas in order to compare effects of water depth, weather, and temporal factors. Previous investigators compared vastly different habitats (e.g., Quinlan and Baldassarre, 1984; Rave, 1987; Rave and Baldassarre, 1989), where extreme variance in teal behavior would be most likely, but effects of specific habitat factors could not be assessed adequately.

Weekly observations of BWT and GWT were made concurrently at three stations from October 1987 to March 1988. Observations were made from 15 minutes before sunrise to 15 minutes after sunset. Days were divided into three equal time blocks (morning, midday, and afternoon), and each time block was divided into equal numbers of 15-minute time periods. Random numbers tables were used to select 30 to 36 observation periods per tower each day.

A single scan was made during selected 15-minute time periods with a 60x spotting scope using scan sampling techniques (*sensu* Baldassarre *et al.*, 1988), and all BWT and GWT within 200 m were included in the observations. The activities (*sensu* Paulus, 1988) were recorded on tally meters as resting (sleeping and loafing), feeding (ingestion of surface or subsurface food), locomotion (swimming, walking, or flying), courting (pair formation and social displays), preening (body maintenance or bathing), alert (attentive to disturbance), and agonistic activities (threat displays). The sex of each individual was recorded. All teal within view were counted during every 15-minute period to estimate number of teal using the study areas.

During each 15-minute observation period, ambient temperature, cloud cover, wind velocity, rainfall intensity, and light intensity were recorded. Light was measured with an Environmental Concepts LIM 2300 light-intensity meter mounted on a ring stand to measure reflected light from a photographic gray card. Percent cloud cover was estimated by the observer at Station 2, and wind velocity was measured by an anemometer at the Rockefeller SWR weather station.

Analysis of variance (ANOVA) and Duncan's multiple range test were used to test for significant differences among activities, time blocks, and months. Activities were compared among stations using ANOVA and Duncan's test (BWT: Stations 1 to 3, $n = 297, 254, 196$; GWT: Stations 1 to 3, $n = 264, 368, 135$). Specific activities and differences between sexes (paired sets) of the two species were tested with *t*-tests. Percent-time data were arcsine transformed for these analyses. Numbers of individuals were totaled for each time block, then percent time spent in each activity was calculated by dividing the number of observations of an activity by the total number of observations, times one hundred. Pearson's correlation analyses were used to determine relationships between activities and physical variables. Progressive values were used for correlations involving factors of time: 1 to 6 for months, and 1 to 3 for daily time periods (morning, midday, afternoon). To compare the variables of habitat and how they affected each species, principal components analyses were conducted on untransformed data to determine which physical factors varied most with activities.

RESULTS

Activities

Observations of BWT and GWT totaled 424 hours (no occurrence was not recorded as time). Throughout most of the study, there were more males than females of BWT (9:1) and GWT (10:1) observed; however, there were no significant differences ($P > 0.05$) between sexes in time spent in any activity. Sex of BWT could not be confidently determined during October and early November, because most BWT individuals were in eclipse plumage. Male and female BWT observed after November were not significantly different in their activities. Thus, sexes were not distinguished in the analyses below.

Generally BWT spent more time ($P < 0.01$) feeding (65.4%), more time ($P < 0.05$) alert (3.1%), and less time ($P < 0.01$) resting (15.8%) than GWT (Table 1). There were no differences ($P > 0.05$) between the species in locomoting, courting, or preening activities. Feeding (BWT: 18.4 to 75.8%; GWT: 10.5 to 77.7%) was the most frequent activity of these species ($P < 0.05$) during most months, followed by resting (8.2 to 50.9%; 5.0 to 64.1%) and locomotion (8.2 to 40.7%; 5.5 to 25.5%). Neither species spent much time courting (until March) or alert. Agonistic behavior never represented over 0.12% of activities per month, and therefore was excluded from further analyses.

Habitat Comparisons

Stations 1 and 2 were generally similar habitats, but Station 3 had deeper water and some different vegetation. However, the only significant differences ($F = 6.47, 2 \text{ d.f.}, P < 0.05$) in activities among the three stations occurred in BWT during December and January, when BWT at Station 2 fed less than those elsewhere (Table 2). Numbers of BWT at Station 2 (15,533 observed) greatly exceeded those at Stations 1 (5919) and 3 (5922). GWT were also more numerous at Station 2 (36,782) than at either Stations 1 (7825) or 3 (3356). Relatively few BWT or GWT were observed at Station 3 after December, probably due to high water (greater than 1 m depth).

Temporal Effects

During October, most BWT and GWT had a regular pattern of morning feeding, resting during midday, and preening for up to an hour thereafter. Few BWT or GWT were seen using the study areas when the observers arrived before dawn, but teal began arriving soon thereafter. During October and November, many BWT and GWT were observed leaving the observation areas at Stations 1 and 3

TABLE 1
Activity budgets by month for Blue-winged Teal and Green-winged Teal wintering at Rockefeller SWR, (Cameron Parish, Louisiana).

Blue-winged Teal						
Activity	October	November	December	January	February	March
Resting	15.6 ^a	14.1 ^a	9.0 ^a	8.2 ^a	14.1 ^a	50.9 ^b
Feeding	66.0 ^a	68.3 ^a	43.9 ^b	75.8 ^a	64.8 ^{ab}	18.4 ^c
Locomotion	8.2 ^a	8.4 ^a	40.7 ^b	10.3 ^a	11.8 ^a	10.9 ^a
Courting	0.5	0	0	0.3	1.3	6.0
Preening	5.9	8.8	1.9	4.6	7.0	12.2
Alert	3.8	0.4	4.5	0.8	1.0	1.7
Mean*						15.8
						65.4
						8.8
						0.6
						6.2
						3.1
Green-winged Teal						
Activity	October	November	December	January	February	March
Resting	25.6 ^a	5.0 ^b	64.1 ^c	32.2 ^{ab}	7.2 ^b	35.0 ^c
Feeding	56.9 ^a	76.9 ^a	10.5 ^b	51.8 ^a	77.7 ^a	29.3 ^b
Locomotion	5.5 ^a	11.8 ^b	19.8 ^b	11.0 ^b	9.1 ^{ab}	25.5 ^c
Courting	0	0	0.3	2.0	1.2	2.8
Preening	8.0 ^a	5.2 ^{ab}	5.2 ^{ab}	2.8 ^{bc}	3.8 ^{bc}	0.9 ^c
Alert	4.0	1.1	0	0.1	1.0	6.6
Mean*						27.1
						55.3
						10.5
						1.0
						4.8
						1.3

a,b,c Percentages for each month denoted by different letters are significantly different ($P \leq 0.05$).

* Calculated from total numbers of individuals observed.

TABLE 2

Activity budgets by month and station for Blue-winged Teal (BWT) and Green-winged Teal (GWT) wintering at Rockefeller SWR, Louisiana.

Activity Station	October	November	December	January	February	March
Resting						
1 (BWT)	18.2	8.5	2.5	7.3	17.1	50.1
1 (GWT)	43.6	10.7	--	9.4	15.0	34.9
2 (BWT)	15.7	8.2	17.9	28.3	7.2	--
2 (GWT)	14.6	2.9	64.2	33.0	5.1	--
3 (BWT)	13.9	19.5	0	0	--	--
3 (GWT)	15.8	10.2	0	82.4	--	--
Feeding						
1 (BWT)	46.0	70.9	70.0 ^a	76.9 ^a	63.7	18.4
1 (GWT)	31.0	71.0	--	71.6	70.7	29.3
2 (BWT)	69.2	67.4	11.9 ^b	41.7 ^b	67.5	--
2 (GWT)	75.4	78.1	10.5	51.1	79.6	--
3 (BWT)	68.6	68.3	50.0 ^a	96.2 ^a	--	--
3 (GWT)	66.3	77.3	0	11.8	--	--
Locomotion						
1 (BWT)	12.5	15.0	18.8	9.9	9.6	10.9
1 (GWT)	8.2	12.2	--	15.7	6.5	25.5
2 (BWT)	9.1	14.5	68.7	26.7	17.0	--
2 (GWT)	4.5	12.1	19.8	10.9	9.8	--
3 (BWT)	2.9	2.7	25.0	0	--	--
3 (GWT)	3.0	9.4	0	0	--	--
Courting						
1 (BWT)	2.6	0	0	0.1	1.9	6.0
1 (GWT)	0	0	--	0	1.2	2.8
2 (BWT)	0	0	0	0	0	--
2 (GWT)	0	0	0.3	2.1	1.2	--
3 (BWT)	0.7	0	0	3.9	--	--
3 (GWT)	0.1	0	0	0	--	--
Preening						
1 (BWT)	13.5	3.2	0	4.9	7.4	12.2
1 (GWT)	10.7	4.0	--	2.0	6.3	0.9
2 (BWT)	2.9	9.7	1.5	3.3	6.0	--
2 (GWT)	4.9	5.8	5.2	2.9	3.2	--
3 (BWT)	10.0	9.6	25.0	0	--	--
3 (GWT)	9.1	3.2	99.0	5.9	--	--
Alert						
1 (BWT)	7.2	2.4	8.8	0.9	0.4	1.7
1 (GWT)	6.6	2.1	--	1.3	0.3	6.6
2 (BWT)	3.0	0.2	0	0	2.4	--
2 (GWT)	0.6	1.0	0	0.1	1.2	--
3 (BWT)	3.9	0	0	0	--	--
3 (GWT)	5.8	0	1.0	0	--	--

a,b,c Percentages for each station denoted by different letters are significantly different ($P \leq 0.05$).

after morning feeding, presumably to rest elsewhere. Hundreds of BWT and GWT were observed resting in densely vegetated salt marsh areas (outside the study area) near Station 3 during midday. Similarly, most resting within the observation areas occurred during midday (Table 3).

The greatest differences in activities between the two species occurred during December, when GWT spent 64.1% of the time resting and BWT spent only 9% of the time resting (Table 1). After December, BWT and GWT locomotion was most frequent during morning (Table 3). Time spent courting and alert did not differ ($P > 0.05$) among time blocks in either species.

Physical and Biological Factors

Generally BWT and GWT responded to physical conditions in similar manners. In both species, resting and feeding were highly correlated (BWT: $n = 747$; GWT: $n = 767$; $P < 0.01$) with temperature (+) and light intensity (-). Locomotion was highly correlated with light intensity (-), and preening was highly correlated with temperature (+; Table 4). However, the responses of the two species to physical conditions were not identical. Locomotion was highly correlated with rainfall intensity (+) only in BWT. Preening was most closely correlated with time of day in BWT, but not so in GWT. Courting by GWT was related ($P < 0.01$) to both temperature (-) and light intensity (-), but the factors were not related ($P > 0.05$) in BWT. The significant relationships among feeding, resting, preening, temperature, and light support the observations of teal resting and preening after morning feeding. The consistent pattern of afternoon preening during early months of the study accounted for the inverse relationship ($P < 0.01$) between preening and date. Not unexpectedly, courting increased ($P < 0.01$) during the study period (Table 4) and was most frequent in March (Table 1).

Principal components analysis was conducted on a matrix of percent time spent per activity and physical variables including data from all stations and time blocks. The BWT first principal component (PC-I) showed loadings with five variables: water depth, month, temperature, light intensity, and cloud cover (Table 5). In GWT, the first principal component (PC-I) showed high correlation with four variables: month, temperature, light intensity, and cloud cover (Table 5). The correlation with so many variables indicates that the activities of both species generally varied as a group. PC-II was not highly correlated with any variables. Thus, most separation of the BWT and GWT activities occurred along a single axis (vertical) when the first two principal component scores were plotted in two dimensions (Figure 1). In both species, feeding and resting were separated from other activities, indicating that physical data (especially temperature and light intensity, Table 4) were very useful in interpreting teal feeding and resting

behavior. Several factors (cloud cover, time, temperature, and light intensity) also distinguished the activities (horizontally), but to a lesser degree. Together PC-I and PC-II accounted for 36.7% of the variance in BWT and 35.4% in GWT.

DISCUSSION

Feeding values of BWT (65.4%) were similar to those reported during postbreeding (68.6%, DuBow, 1985) and incubating (60%, Miller, 1976), and GWT values (55.3%) were similar to those for GWT feeding in natural marshes of South Carolina (56%, Hepp, 1982). However, GWT feeding values were well above averages reported elsewhere along the Gulf Coast (Texas, $< 23\%$, Quinlan and Baldassarre, 1984; Louisiana, 33.3%, Rave and Baldassarre, 1989). Some of the discrepancy among studies likely resulted from variation in the habitats studied. For example, studies in Texas were conducted in agricultural areas where less foraging may be necessary to meet metabolic needs ($< 23\%$, Quinlan and Baldassarre, 1984). Also, inclusion of several habitats in a study may lower the overall values for time spent feeding, assuming the activities vary with habitat. We used only intermediate marshes for our study. Rave and Baldassarre (1989), who also studied GWT on Rockefeller SWR, observed at several habitats, including intermediate marshes where GWT fed 41.3% of the time.

Overall, BWT spent more time feeding (65.4%) than GWT (55.3%). Bellrose (1980) reported that these two teal species often feed together, although GWT have a greater preference for seeds, and species that feed on seeds may allocate less time to feeding (Paulus, 1984). Gut contents of BWT and GWT collected during the study period indicated they fed on similar diets, primarily of wild seeds and chironomids, and seldom ingested agricultural seeds. Therefore, though the differences between the two species in time spent feeding could have resulted solely from greater preference for seeds by GWT, we suggest that the differences resulted from discrepancies in selections of habitats as well.

The frequency of feeding and locomotion of both species increased with decreasing temperatures (Table 4), probably a response to greater metabolic needs (Jorde *et al.*, 1983), but perhaps also because food availability decreased from fall to winter. At Rockefeller SWR, chironomid and seed densities diminished from fall to winter in the three study areas (Gaston and Nasci, 1989). Mean number of chironomids during fall (October to December) was 912 m^{-2} (range 20 to 2422 m^{-2}), while winter (January and February) means were 365 chironomids m^{-2} (range, 60 to 760 m^{-2}). Total number of seeds averaged 8917 m^{-2} during the fall (range, 1240 to 23,660 m^{-2}) and 4075 m^{-2} (range, 2400 to 6650 m^{-2}) during the winter.

TABLE 3

Activity budgets by month and time of day for Blue-winged Teal (BWT) and Green-winged Teal (GWT) wintering at Rockefeller SWR, Louisiana.

Activity Time	October	November	December	January	February	March
Resting (BWT)						
Morning	6.2	12.7	0	10.8	15.4	23.9
Midday	26.2	14.7	30.0	6.9	7.9	70.0
Afternoon	15.9	26.6	6.9	17.7	29.7	42.1
Resting (GWT)						
Morning	11.9 ^a	9.0 ^a	15.1 ^a	13.4 ^a	16.7 ^a	--
Midday	63.3 ^b	18.6 ^b	48.8 ^b	37.7 ^b	5.6 ^b	--
Afternoon	15.5 ^a	12.2 ^b	52.2 ^b	18.8 ^a	21.5 ^a	29.8
Feeding (BWT)						
Morning	76.8 ^a	70.8 ^a	72.0 ^a	71.0 ^a	45.4 ^a	30.8 ^a
Midday	54.8 ^b	72.1 ^a	30.0 ^b	66.6 ^b	77.1 ^b	8.9 ^b
Afternoon	60.9 ^b	55.3 ^b	29.6 ^b	62.7 ^b	53.9 ^a	23.6 ^b
Feeding (GWT)						
Morning	76.1 ^a	68.6 ^a	50.0 ^a	59.5 ^a	53.4 ^a	--
Midday	25.3 ^b	48.5 ^b	24.4 ^b	43.6 ^b	84.2 ^b	--
Afternoon	63.6 ^a	67.8 ^a	25.1 ^b	64.8 ^a	63.3 ^a	26.7
Locomotion (BWT)						
Morning	8.8	13.1 ^a	14.6 ^a	17.9 ^a	25.9 ^a	23.2 ^a
Midday	10.1	2.6 ^b	40.0 ^b	16.3 ^a	8.1 ^b	6.3 ^b
Afternoon	8.7	11.7 ^b	51.5 ^b	7.9 ^b	7.6 ^b	12.6 ^b
Locomotion (GWT)						
Morning	4.8	17.6 ^a	21.1	21.0	22.8 ^a	--
Midday	0.9	25.7 ^b	21.4	15.5	5.0 ^b	--
Afternoon	7.1	14.3 ^a	19.4	10.0	6.6 ^b	33.2
Courting (BWT)						
Morning	0.3	0	0	0	2.6	12.6
Midday	0.8	0	0	4.2	0.6	3.0
Afternoon	0.3	0	0	0.2	0.6	5.4
Courting (GWT)						
Morning	0	0	0.1	4.0	1.3	--
Midday	0.1	0	0.8	0.9	1.3	--
Afternoon	0.1	0	0	0.8	0.8	2.7
Preening (BWT)						
Morning	3.4	2.5	0	0.2	7.9	9.5
Midday	6.8	10.6	0	1.4	3.5	11.4
Afternoon	9.3	6.3	6.3	11.2	7.4	12.9
Preening (GWT)						
Morning	4.5 ^a	4.7	13.7 ^a	1.8	3.2	--
Midday	9.3 ^b	6.1	4.6 ^b	1.2	3.8	--
Afternoon	8.7 ^b	4.5	3.4 ^b	4.0	7.4	0.9
Alert (BWT)						
Morning	4.5	0.9	13.4	0.1	2.8	0
Midday	1.2	0	0	4.6	2.9	0.4
Afternoon	4.8	0	5.6	0.3	0.9	3.3
Alert (GWT)						
Morning	2.6	0	0	0.3	2.6	--
Midday	1.1	1.1	0	1.1	0.1	--
Afternoon	5.1	1.2	0	1.5	0.4	6.7

a,b Percentages for each time of day denoted by different letters are significantly different ($P \leq 0.05$).

TABLE 4
Correlation coefficients of selected physical variables and activities of Blue-winged Teal and Green-winged Teal wintering at Rockefeller SWR, Louisiana.

Variable	Blue-winged Teal					
	Resting	Feeding	Locomotion	Courting	Preening	Alert
Date	0.073	-0.087*	0.106*	0.139**	-0.001	-0.028
Time	0.102*	-0.142*	-0.047	-0.026	0.172**	0.034
Rainfall	-0.045	-0.022	0.238**	-0.026	-0.086*	0.053
Wind	-0.005	0.007	-0.107*	-0.060	0.081*	-0.021
Temperature	0.186**	-0.193**	-0.121**	0.011	0.139**	0.028
Light intensity	0.138**	-0.118**	-0.141**	-0.005	0.085*	-0.015
Cloud Cover	-0.144**	0.076	0.141**	-0.056	-0.047	0.050

Variable	Green-winged Teal					
	Resting	Feeding	Locomotion	Courting	Preening	Alert
Date	-0.062	-0.055	0.156**	0.241**	-0.125**	-0.065
Time	0.047	-0.032	-0.097*	-0.105*	0.036	0.091*
Rainfall	0.004	-0.073	0.059	0.077	0.027	-0.003
Wind	-0.059	0.063	-0.085*	-0.062	0.005	0.009
Temperature	0.213**	-0.127**	-0.063	-0.159**	0.155**	0.030
Light intensity	0.393**	-0.210**	-0.158**	-0.136**	0.151**	-0.027
Cloud Cover	-0.112*	0.002	0.010	0.057	-0.018	0.053

* P < 0.05

** P < 0.01

Activity budgets of BWT and GWT were similar among the three areas we studied, even though the habitats varied somewhat in water depth and related variables. We had much less habitat diversity for comparisons than in previous studies in Texas (White and James, 1978), Alabama (Turnbull and Baldassarre, 1987), or Louisiana (Rave and Baldassarre, 1989) where investigators demonstrated significant differences in activity budgets of waterfowl using widely different habitats.

The inverse relationship between feeding and temperature (Table 4) stresses the impact of cold fronts, morning low temperatures, and decreasing temperatures on teal

activities. Highest numbers of BWT were observed during October and November, indicating that most of them were on migration flights and later left the area. Thus, since many of the BWT probably arrived in the study areas in association with weather fronts (as suggested by Bellrose, 1980), the relationship between feeding and temperature was not unexpected. The lack of close correlations between time of day and feeding or resting of the teal (Table 4) emphasizes the loss of pattern in activities after fall. We suggest this occurred because metabolic demands increased after December, and because seeds and chironomids, which had been abundant in the study areas during the fall, were more

TABLE 5

Correlations with first and second principal components based on physical variables and activities of Blue-winged Teal and Green-winged Teal wintering in southwestern Louisiana.

Physical Variables	Blue-winged Teal		Green-winged Teal	
	PC-I	PC-II	PC-I	PC-II
Water Depth	-0.51	-0.33	-0.27	-0.11
Date	0.73	0.33	0.78	0.22
Time	-0.31	0.30	-0.24	-0.23
Rainfall Intensity	0.50	0.11	0.40	0.34
Wind Velocity	-0.03	0.08	0.01	-0.31
Temperature	-0.84	0.16	-0.84	-0.02
Light Intensity	-0.79	0.03	-0.84	0.08
Cloud Cover	0.69	0.02	0.62	0.04

scarce after December. This scarcity in food probably accounted for the increased time spent in locomotion during late winter and early spring mornings (Table 3). Apparently, since food was scarce, the BWT and GWT spent more time in search of feeding areas or spent more time feeding elsewhere.

Both teal species fed more during the mornings than during the afternoons. This pattern was especially evident during the fall (Table 3) when thousands of migrating BWT actively fed in the area. Several hypotheses could be proposed to explain the pattern of morning feeding. Perhaps some teal were arriving during morning (migrants) or were fasting overnight, as proposed by Rave and Baldassarre (1989). Perhaps most of the teal left the study area after morning feeding, and those that remained fed little because they had met their metabolic requirements. Perhaps morning feeding was more efficacious than midday or afternoon feeding because of less predation pressure during morning.

Euliss and Harris (1987) hypothesized that disturbance by Northern Harriers (*Circus cyaneus*) played a major role in diurnal activities of GWT. However, Gadwalls (*Anas strepera*) feeding in the same study area were not disturbed by the presence of Northern Harriers (Gaston and Nasci, 1989). We observed that Northern Harriers caused both BWT and GWT in our study areas to take flight regularly, and Northern Harriers were especially active during midday and afternoon. Significantly greater morning feeding by these teal is consistent with the hypothesis that predation pressure influenced the time of day that teal fed, and may account for the use of refuge vegetation during resting periods.

There were differences in overall time spent feeding, resting, and alert between BWT and GWT, but the daily and monthly patterns in activities were generally similar and the role of habitat remained unchanged during the study. The study area provided resources for both species, and both apparently used the area for most of their feeding. However, BWT and GWT responded differently to certain environmental and habitat conditions. As food was depleted during middle and late winter, many GWT left the shallow intermediate marsh ponds and fed in salt marsh mudflats (see Gaston, 1992). Those BWT and GWT that remained in the study area spent more time foraging for diminishing resources. During our study, many GWT used salt marshes for midday resting and preening. BWT did not use mudflats or salt marsh areas as often, and either used the intermediate marshes for all of their activities or emigrated from the study area (i.e., across the Gulf of Mexico).

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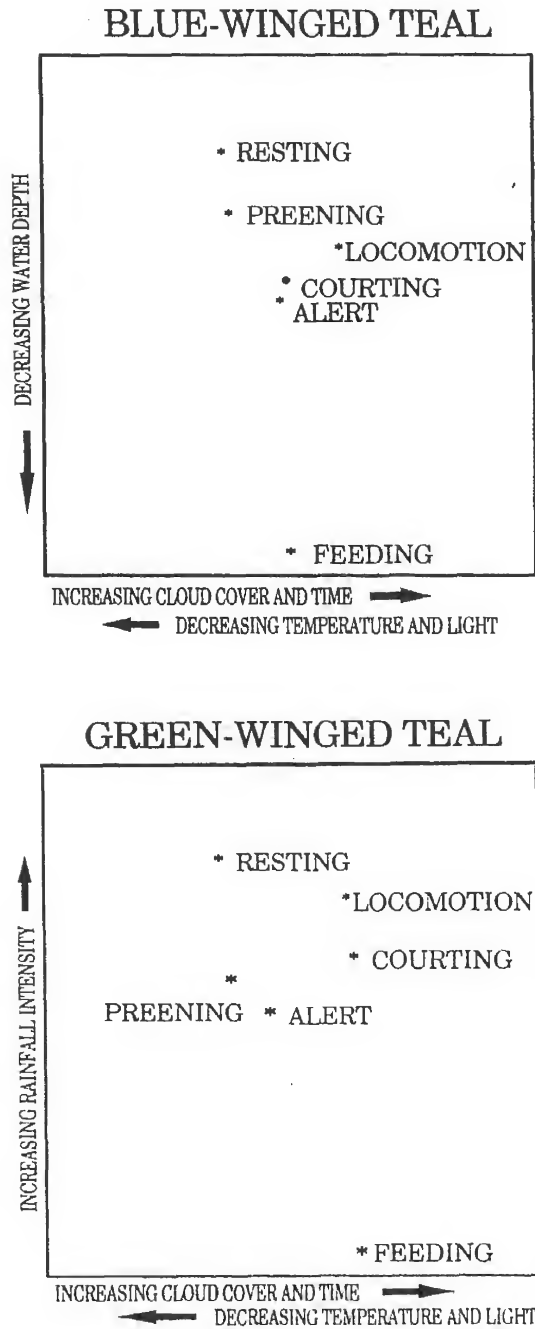


Figure 1. First (abscissa) and second (ordinate) unrotated eigenvectors of a principal components analysis of Blue-winged Teal and Green-winged Teal activities and associated physical variables in southwestern Louisiana.

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FATTY ACID PATTERN DIFFERENCES AMONG INDIVIDUALS OF TWO ESTUARINE FISHES (*LEIOSTOMUS XANTHURUS* AND *MUGIL CEPHALUS*)

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ABSTRACT Ten individual fish of two estuarine species, spot (*Leiostomus xanthurus*) and striped mullet (*Mugil cephalus*), were analyzed for fatty acids. Fish of similar size were obtained from a single collection to minimize variability due to age, size, location and season. Analysis of variance (ANOVA) of each fatty acid provided statistically similar groups for each acid that existed among individual fish. Fatty acids in the striped mullet provided a greater number of statistically similar groups than those in spot, indicating greater variability among individual striped mullet, which probably reflected a greater diversity in the feeding regime for this species. ANOVA results within classes of fatty acids of both species indicated greater diversity in monounsaturated and polyunsaturated than saturated fatty acids. Eicosapentaenoic acid (EPA) showed more individual variability in both species than did docosahexaenoic acid (DHA). Dietary lipids and metabolic needs of the two species are distinct and may be the key factors in explaining individual differences observed in these two fish species.

INTRODUCTION

Natural populations of fishes contain fatty acids and other nutritional components that are highly variable. Stansby (1981) has addressed some sources of variability in fatty acid composition of fish oils within a given species. Other studies have focused on individual species and variations with respect to age (Hayashi and Takagi, 1978), season (Ueda, 1976; Hayashi and Takagi, 1977, 1978; Gallagher *et al.*, 1989), size (Gallagher *et al.*, 1984) and geographical location (Addison *et al.*, 1973; Whyte and Boutillier, 1991), but have not addressed variations among individuals of these species. Assessing importance of these variables is dependent upon appraisal of individual variability, since inherent biochemical differences exist from fish to fish even when all other variables are minimized. It was essential that specimens be carefully selected of two species of coastal Gulf finfishes which differed little in size, development stage, weight or location of catch. This selection permitted specific examination of those fluctuations in individual fatty acids that may occur due only to individual differences. By using a non-random selection process for samples, results could not be used to characterize overall trends in the two species. However, it was felt that results would define some individual variations that are uniquely characteristic for these two fishes that would permit informative and useful comparisons to be made and that suggestions for these variability differences would be suitable.

Two species of coastal Gulf finfishes, spot and striped mullet, were chosen for assessing individual variability because they met several criteria. They represented fishes with different feeding regimes, they were collected easily

in large numbers from a given area in one catch, and they were numerous enough to permit selection of fish having little variation in size. Additionally, the biology of spot (Gunter, 1945; Dawson, 1958; Hodson *et al.*, 1981; Chestnut, 1983; Sheridan *et al.*, 1984) and striped mullet (Odom, 1966; Thompson, 1966) is well established, and both species are found abundantly in local coastal estuaries.

Spot is a dominant bottom fish and is considered to feed in schools over sand-mud bottoms on polychaetes, harpacticoid copepods, bivalves and possibly some detritus (Hildebrand and Schroeder, 1928; Darnell, 1958; Hodson *et al.*, 1981). Spot has a fairly small mouth and possesses gill rakers that permit retention of small food particles and prevent ingestion of relatively large food items such as fish, shrimp and crabs (Darnell, 1958; Hodson *et al.*, 1981; Chestnut, 1983; Sheridan *et al.*, 1984).

On the other hand, the striped mullet begins its life by eating planktonic plants and animals, but it changes its diet to include a broad range of detritus and plant material as it develops (Moore, 1974). It filter-feeds above organic muds containing microplant material and macroplant detritus (Odom, 1966, 1970), and it is generally considered to be a broad spectrum herbivore. Occasionally, however, carnivorous feeding has been observed in striped mullet (Bishop and Miglarese, 1978).

Fatty acids in marine dietary lipids, whether plant or animal, serve as an energy source for metabolism and provide polyunsaturated fatty acids (PUFA) essential for membrane structure and function. Lipids in muscle tissue of fish generally reflect those fatty acids obtained from the diet. Since these two species have a widely different natural diet, they provide an opportunity to examine individual variability within and between species.

MATERIALS AND METHODS

Collection

Striped mullet were collected on January 21, 1988 in the shallow estuary of Biloxi Bay, Mississippi. Spot were collected on April 13, 1988 at Ship Island, a barrier island 15 miles south of Gulfport, Mississippi, in the northeastern Gulf of Mexico. All fish were collected by gill net and maintained on ice until examined. Standard lengths were measured and weights recorded. Fish of approximately the same size were filleted and individual fish placed separately in polyethylene bags, flushed with N_2 , rapidly frozen and stored at -20°C . Average body weight of striped mullet was 230 g ($\pm 12\%$ relative standard deviation; RSD) and average standard length was 221 mm ($\pm 4.5\%$ RSD). Average body weight of spot was 147 g ($\pm 5.2\%$ RSD), and average standard length was 174 mm ($\pm 3.5\%$ RSD).

Analytical Procedure

All solvents used in analysis were HPLC grade or analytical reagent grade. Standards were purchased from NuCheck Prep, Inc. (Elysian, MN). Fillets were homogenized using a Waring blender and 0.5 g aliquots weighed into screw-capped (Teflon-lined) centrifuge tubes (30 ml) and saponified at ambient temperature with ethanolic KOH under N_2 using a magnetic stirrer for one hour. Care was exercised in the volumes of saponifying mixtures used to keep the water level, derived from tissue, sufficiently high to prevent trans-esterification. Solvent ratios were those suggested by Nelson (1966). After dilution with distilled water, the neutral fraction was extracted with hexane. The remaining alkaline solution was acidified with 6N HCl, and free fatty acids were extracted with benzene. Benzene aliquots were combined and concentrated using a rotary evaporator. All evaporations were closely monitored to ensure that distillation temperatures did not exceed 25°C . Fatty acids were converted to methyl esters using 7% BF_3 -MeOH by the method of Metcalfe *et al.* (1966) modified to use ambient temperatures and a one-hour reaction period.

Identification of fatty acid methyl esters (FAME) was obtained by capillary gas chromatography (GC) using a Perkin-Elmer model Sigma 2000 gas chromatograph equipped with flame ionization detector and fitted with a 30 m x 0.25 mm i.d. fused silica capillary column coated with a 0.25 μm film thickness of Dura Bond WAX (J & W Scientific) and operated with a split ratio of 100:1. The carrier gas, He, was maintained at 20 psi. Oven temperature was programmed at 90 – 250°C at a linear rate of $4^\circ/\text{minute}$. Data was processed using a Perkin-Elmer Sigma 10 data system with quantification of all compounds based on individual peak area response by GC compared to the

internal standard methyl tricosanoate. Quantitative data were corrected for differences in detector responses that were determined through analysis of authentic standards of each reported fatty acid. FAME were tentatively identified by comparison with retention times with those of authentic standards. Verification of identification on select samples was accomplished through gas chromatography mass spectrometry analysis conducted by National Marine Fisheries Service, Charleston Laboratory. Concentrations of individual isomers of PUFA were separately tabulated; separate isomers of monounsaturates (e.g. 18:1) were not reported.

Sample Protection

Several precautions were taken to ensure that no degradation or other alteration of lipids occurred during extraction and saponification. All analytical steps were conducted at ambient temperatures, and samples were constantly flushed with N_2 to prevent oxidation. Further, as many steps as possible were conducted in a single extraction tube to reduce loss and degradation that occurs with sample transfer. All solvents were flushed with N_2 immediately before use to remove dissolved O_2 and to prevent oxidative degradation. Likewise, samples requiring storage were placed in sample bags which were flushed with N_2 before being frozen (-20°C). In addition, the antioxidant butylated hydroxytoluene (BHT) was added in a concentration of 0.005% (w/v) to extraction solvents to prevent oxidative degradation of unsaturated lipids.

Data Analysis

One way analysis of variance (ANOVA) with *post facto* 95% confidence level range test (Statistical Graphics Corporation, 1988) was used to compare individual fatty acids as well as certain parameters derived from fatty acid data of individual fish. Similarity groups were established of individuals for each variable which were statistically indistinguishable ($p < 0.05$). In addition, the number of groups was tallied as a further measure of individual variability.

RESULTS

Figures 1 and 2 depict mean concentration of fatty acids in the samples of individual spot and striped mullet as well as mean % composition of total saturated, monounsaturated and PUFA. Figures 1 and 2 also include the standard deviations of the means of the ten individual fish and are shown by the dark bars in the graphs. Concentrations are shown in both wt% of the total fatty acids and

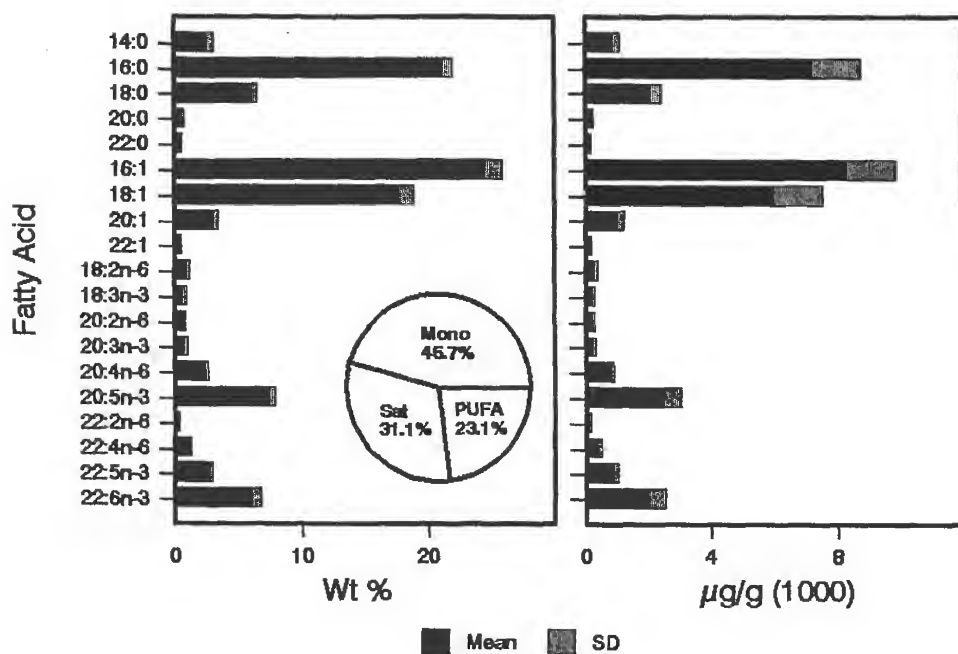


Figure 1. *Leiostomus xanthurus*. Distribution of fatty acids in spot. Empty bars to the left represent mean concentrations in wt% of total reported fatty acids of 10 individual fish. Bars to the right depict mean concentrations in µg/g (wet tissue). Gray bars are standard deviations computed on the mean of the 10 mean values for individual fish.

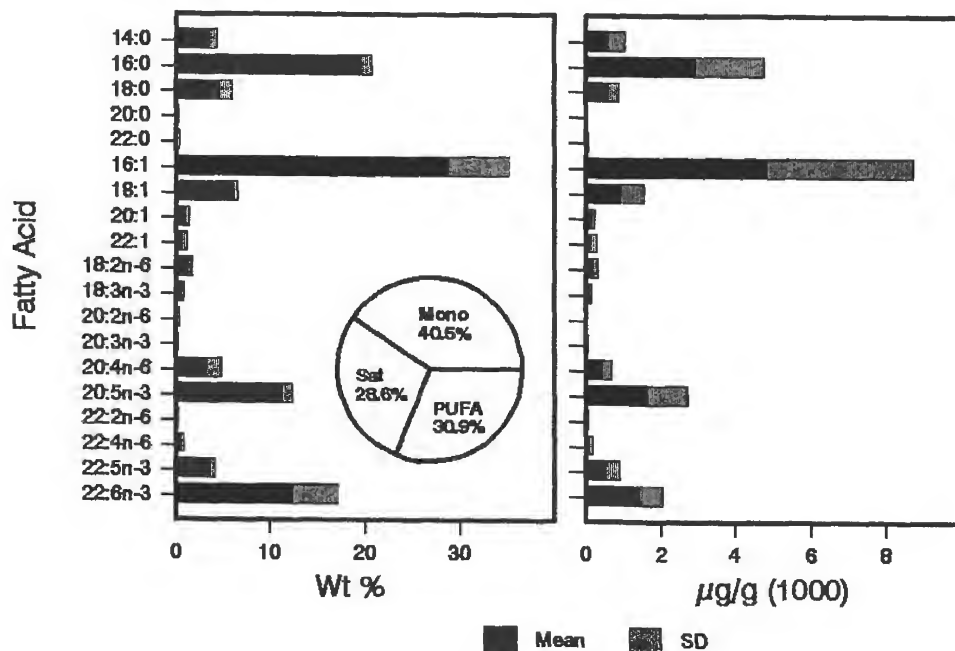


Figure 2. *Mugil cephalus*. Distribution of fatty acids in striped mullet. See caption for Figure 1.

in absolute concentrations of $\mu\text{g/g}$ of wet tissue. Absolute concentrations are useful when assessing muscle tissue for nutritive value, particularly for omega-3 (n-3) content, since there is an increased interest in possible health benefits (Lands, 1986), while weight percent concentrations are useful in assessing biochemical significance of fatty acid distributions.

Tables 1 and 2 contain fatty acid data computed on a wt % basis for fatty acids in muscle tissue from spot and striped mullet, respectively. Also included are summations and ratios that are helpful in characterizing fatty acid profiles in finfish. Superscripts signify the statistically similar group(s) that each individual fish falls within for ANOVA treatment of each fatty acid or fatty acid parameter. At the end of each row is the number of groups produced by ANOVA examination of that fatty acid.

Individuals of both species varied in fat content. Striped mullet ranged from 1.82-6.38%, while spot ranged from 4.75-8.10%.

Fatty Acid Distribution in Spot and Striped Mullet

Fatty acid profiles (Figures 1 and 2) were similar from both species, particularly in content of saturated fatty acids. Hexadecanoic acid (16:0) was dominant, followed in decreasing order by octadecanoic acid (18:0) and tetradecanoic acid (14:0). The remaining saturated acids constituted less than one percent of the total fatty acids. The predominant monounsaturated acid in both fish was 16:1. Relative to 16:1, the contents of 18:1 and 20:1 acids were higher in spot than in striped mullet, whether expressed in wt% or $\mu\text{g/g}$. The two principal PUFA in both fishes were eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3). These n-3 PUFA constitute a higher percentage of the total fatty acids of striped mullet (23.7%) than the spot (13.5%), although in absolute concentration, these PUFA are enriched in spot (4,530 $\mu\text{g/g}$) relative to striped mullet (3,120 $\mu\text{g/g}$). A narrow range (2.25 to 2.86%) as well as low concentration of arachidonic acid (AA, 20:4n-6) was found in spot, whereas a wider range and higher concentrations (1.70-7.00%) were found in striped mullet.

Statistical Comparisons of Component Fatty Acids

Octadecanoic acid, 18:0, was the second most dominant saturated fatty acid in both spot and striped mullet. In spot, no significant difference in values was found among any of the individual fish (i.e. only one similarity group shown in Table 1). On the other hand, there were seven statistically similar groups for 18:0 in striped mullet (Table 2). Minor saturated components, 20:0 and 22:0 in striped mullet (22:0 in spot), showed no significant differ-

ences among any of the ten individual fish. Except for 22:1 in spot, each monounsaturate in both spot and striped mullet showed high diversity among individual fish (four to six similarity groups). Among the PUFA, there were more ANOVA similarity groups for EPA in both spot and striped mullet than for DHA, indicating a greater diversity of EPA than DHA in muscle tissue. In striped mullet, ANOVA treatment of arachidonic (20:4n-6), linolenic (18:3n-3) and octadecanoic acid (18:0) each produced seven similarity groups, the most diverse fatty acids in either fish.

Fatty Acid Classes

Figures 1 and 2 indicate that both fishes showed a prevalence of monounsaturates, with spot having 46% monounsaturated, 23% PUFA and 31% saturated, as compared to 40%, 31%, and 29%, respectively, for these fatty acid classes in striped mullet. The saturates for both fishes were less diverse than for either the monounsaturates or PUFA. Likewise, the average value of ANOVA similarity groups for individual saturated fatty acids was less than that found for either of the other fatty acid classes in both spot and striped mullet.

Fatty acids occurring in concentrations above 1% of total fatty acids showed a higher degree of individual variability than fatty acids occurring in less than 1% for both spot and striped mullet. The average number of similarity groups for all fatty acids whose concentrations are above 1% was 3.8 for spot and 5.0 for striped mullet, with 2.5 and 4.3 groups for fatty acids comprising less than 1%.

Fatty Acid Parameters

Total n-3/n-6 ratio showed little variation among individual spot with ANOVA, separating into only two statistically similar groups. Excluding individual spot No. 1, no distinction occurred among individuals (Table 1). Conversely, the separate sums of n-3 and n-6 fatty acids in spot were separated into five and three similarity groups, respectively. The n-3/n-6 ratio also varied less among individual striped mullet (four groups) than the separate total n-3 and total n-6 fatty acid parameters (five and seven groups, respectively). ANOVA treatment applied to total PUFA in both spot and striped mullet produced five similarity groups. In spot, the unsaturated/saturated and (EPA+DHA)/n-3 parameters produced two and four ANOVA groups, but in striped mullet, it was four and six groups. ANOVA treatment separated the calculated parameters of striped mullet into a larger number of groups than those of spot, demonstrating the higher degree of individual diversity for component fatty acids in the striped mullet.

TABLE 1

Leiostomus xanthurus. Fatty acids in spot. Entries are means for three replicate analyses of homogenized muscle tissue from each of 10 individual fish. Values in parentheses are % relative standard deviations. Entries in rows sharing the same superscript letter are not statistically different ($p < 0.05$) and are referred to as similarity groups; group numbers refer to numbers of similarity groups computed for each fatty acid.

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	Groups
	Concentration in wt %										
14:0	1.84 (2.48) ^a	2.21 (2.19) ^b	2.82 (1.29) ^{cd}	2.24 (1.89) ^b	2.78 (1.79) ^{cd}	3.00 (2.81) ^d	3.56 (4.63) ^e	2.70 (3.69) ^e	2.61 (0.527) ^{cd}	2.16 (3.83) ^b	5
16:0	21.4 (0.754) ^{ab,cd}	22.2 (3.53) ^c	20.5 (0.868) ^{ab}	21.3 (1.36) ^{bc}	21.5 (1.36) ^{bc}	20.0 (2.47) ^a	20.3 (2.66) ^a	20.6 (2.94) ^{ab}	21.4 (1.71) ^{abc}	22.6 (1.60) ^c	3
18:0	6.60 (1.76)	6.31 (5.30)	6.07 (6.75)	6.56 (6.62)	5.53 (1.28)	6.76 (8.74)	5.61 (12.3)	6.53 (5.78)	5.04 (6.06)	5.88 (1.02)	1
20:0	0.745 (2.34) ^{ab,cd}	0.453 (41.3) ^{ab}	0.963 (30.2) ^c	0.812 (0.515) ^{bc}	0.640 (16.0) ^{ab,cd}	0.636 (30.4) ^{ab,cd}	0.476 (44.4) ^{ab}	0.578 (31.6) ^{abc}	0.325 (2.32) ^a	0.307 (10.1) ^a	3
22:0	0.503 (24.3)	0.553 (4.26)	0.607 (10.3)	0.628 (5.06)	0.520 (14.9)	0.507 (10.7)	0.606 (12.3)	0.395 (18.1)	0.455 (40.2)	0.514 (4.91)	1
16:1	24.6 (1.99) ^{cd}	24.8 (1.733) ^{bcd}	25.7 (0.349) ^{cd}	21.8 (0.799) ^a	23.7 (3.42) ^{bc}	23.5 (1.65) ^b	26.0 (1.49) ^d	26.8 (3.37) ^d	25.0 (1.41) ^{cd}	23.3 (1.27) ^{ab}	6
18:1	18.0 (1.34) ^{cd}	19.3 (0.831) ^b	16.6 (1.41) ^{ab}	17.0 (6.07) ^{abcd}	17.4 (2.09) ^{abcd}	17.0 (3.26) ^{abcd}	16.9 (1.32) ^{abc}	16.5 (1.01) ^a	17.7 (1.38) ^{cd}	20.3 (0.719) ^d	6
20:1	3.44 (2.10) ^{cd}	2.90 (10.1) ^{ab,cd}	3.31 (1.33) ^{abcd}	3.78 (3.04) ^d	2.98 (9.40) ^{ab,cd}	3.98 (9.13) ^{cd}	3.12 (9.65) ^{abc}	2.76 (10.7) ^{ab}	2.60 (1.86) ^a	2.49 (3.09) ^a	4
22:1	0.516 (28.9)	0.405 (28.9)	0.508 (6.63)	0.517 (28.3)	0.535 (12.4)	0.509 (31.5)	0.484 (13.1)	0.368 (10.6)	0.458 (28.1)	0.582 (10.4)	1
18:2n-6	1.40 (3.82) ^b	0.730 (23.8) ^a	1.18 (21.2) ^{ab}	1.22 (8.29) ^{ab}	0.689 (14.2) ^{ab}	0.933 (26.5) ^{ab}	0.764 (32.7) ^a	1.03 (24.0) ^{ab}	0.712 (8.08) ^a	0.837 (6.35) ^a	2
18:3n-3	0.845 (2.51) ^{abc}	0.449 (62.1) ^{ab}	0.765 (7.25) ^{abc}	1.32 (1.98) ^a	0.505 (51.2) ^{ab}	0.633 (34.8) ^{ab}	0.406 (59.8) ^a	1.10 (51.6) ^{bc}	0.300 (0.900) ^a	0.420 (15.1) ^a	3
20:2n-6	0.877 (5.24) ^a	0.685 (20.5) ^{ab,cd}	0.872 (4.55) ^{bc}	0.963 (1.20) ^a	0.646 (16.7) ^{abc}	0.787 (24.9) ^{bc}	0.623 (33.7) ^{abc}	0.641 (35.1) ^{abc}	0.384 (3.59) ^a	0.479 (19.3) ^{ab}	3
20:3n-3	1.07 (7.27) ^{cd}	0.332 (13.7) ^{ab}	1.01 (5.13) ^{cd}	1.16 (3.32) ^a	0.731 (16.3) ^{bcd}	0.859 (26.6) ^{cd}	0.674 (36.0) ^{bcd}	0.619 (34.6) ^{bc}	0.356 (7.47) ^{ab}	0.206 (18.2) ^a	5
20:4n-6	2.50 (2.34) ^{abcd}	2.28 (3.95) ^{cd}	2.27 (2.04) ^{ab}	2.43 (2.97) ^{abcd}	2.36 (3.60) ^{cd}	2.64 (1.94) ^{cd}	2.25 (4.59) ^{ab}	2.88 (9.95) ^d	2.47 (3.42) ^{abcd}	2.01 (7.45) ^a	4
20:5n-3 (EPA)	7.36 (1.44) ^a	6.70 (2.10) ^a	6.98 (3.00) ^{ab}	8.01 (3.02) ^a	7.45 (2.23) ^{abcd}	8.06 (5.02) ^{cd}	8.22 (4.55) ^d	6.88 (3.57) ^{ab}	7.41 (3.09) ^{bc}	7.21 (1.41) ^{ab}	4
22:2n-6	0.343 (24.3) ^a	0.298 (7.41) ^a	0.232 (32.9) ^a	0.312 (19.2) ^a	0.247 (26.2) ^a	0.193 (41.4) ^a	0.249 (50.6) ^a	0.164 (24.7) ^a	0.216 (44.1) ^a	0.558 (4.62) ^a	2
22:4n-6	1.04 (15.0) ^a	1.17 (2.41) ^{ab}	1.27 (4.41) ^{ab}	1.25 (6.95) ^{ab}	1.28 (7.94) ^{ab}	1.09 (26.6) ^{ab}	1.30 (7.98) ^{ab}	1.07 (6.66) ^{ab}	1.41 (4.55) ^b	1.19 (3.47) ^{ab}	2
22:5n-3	2.25 (4.39) ^a	2.57 (1.60) ^{ab}	2.68 (2.92) ^{bc}	2.98 (5.80) ^{cd}	3.07 (2.70) ^d	2.89 (6.97) ^{cd}	2.73 (5.11) ^{cd}	2.55 (4.86) ^{ab}	3.06 (6.74) ^{cd}	2.24 (3.55) ^a	4
22:5n-3 (DHA)	4.60 (0.637) ^a	5.80 (2.09) ^b	5.59 (2.82) ^{bc}	5.78 (3.80) ^c	7.16 (0.729) ^c	6.68 (6.64) ^c	5.81 (5.54) ^{bc}	5.96 (4.65) ^b	6.87 (2.58) ^c	6.67 (1.26) ^c	3
ΣPUFA	22.3 (1.33) ^{ab}	21.0 (2.30) ^a	22.8 (1.36) ^{bc}	25.5 (3.03) ^c	24.3 (3.21) ^{abcd}	24.7 (1.51) ^{cd}	23.0 (2.80) ^{cd}	22.9 (4.12) ^{bc}	23.2 (2.27) ^{abcd}	21.8 (1.22) ^{ab}	5
Σsaturates	31.1 (1.41) ^a	31.7 (0.967) ^{ab}	31.0 (1.38) ^{ab}	31.5 (0.629) ^a	31.0 (0.704) ^{ab}	31.0 (1.96) ^{ab}	30.8 (1.98) ^a	30.8 (0.627) ^a	31.0 (1.99) ^{ab}	31.5 (1.02) ^{ab}	2
Σmonounsaturates	46.6 (0.912) ^d	47.4 (0.200) ^d	46.2 (0.161) ^{cd}	43.1 (1.39) ^a	44.4 (1.05) ^{bc}	44.4 (0.880) ^{ab}	46.5 (0.397) ^d	46.4 (1.09) ^d	45.8 (0.235) ^{cd}	46.7 (0.514) ^d	4
Σunsat/Σsat	2.21 (1.04) ^{ab}	2.16 (1.59) ^a	2.23 (2.03) ^{ab}	2.17 (0.405) ^{ab}	2.26 (1.02) ^{ab}	2.23 (1.53) ^{ab}	2.28 (2.89) ^{ab}	2.25 (1.22) ^{ab}	2.22 (2.71) ^{ab}	2.17 (1.14) ^{ab}	2
Σn-6	5.13 (3.02) ^c	4.00 (11.0) ^{ab}	4.55 (4.94) ^{abc}	4.92 (2.03) ^{bc}	4.14 (7.19) ^{abc}	4.56 (11.2) ^{abc}	3.68 (12.9) ^a	4.69 (15.1) ^{abc}	3.78 (0.614) ^a	3.88 (7.24) ^{ab}	3
Σn-3	17.2 (2.48) ^a	17.0 (1.05) ^a	18.3 (2.23) ^{abc}	20.5 (3.30) ^c	20.2 (2.55) ^{cd}	20.1 (3.51) ^{cd}	19.1 (2.73) ^{abcd}	18.2 (2.01) ^{abc}	19.4 (2.62) ^{abc}	17.9 (0.433) ^{ab}	5
Σn-3/Σn-6	3.35 (5.33) ^a	4.31 (10.2) ^{ab}	4.03 (3.97) ^{bc}	4.18 (1.51) ^{ab}	4.89 (5.28) ^{bc}	4.49 (15.5) ^{bc}	5.01 (3.6) ^a	3.96 (15.6) ^{ab}	5.13 (2.44) ^b	4.64 (7.49) ^b	2
(EPA+DHA)/n-3 %	41.4 (2.97) ^{ab}	47.4 (0.344) ^{cd}	43.0 (0.283) ^b	40.0 (0.376) ^a	47.2 (1.16) ^{cd}	45.8 (1.61) ^c	42.1 (1.98) ^a	48.5 (0.883) ^d	48.1 (0.990) ^d	48.4 (1.05) ^d	4

TABLE 2

Mugil cephalus. Fatty acids of striped mullet. Entries are means for three replicate analyses of homogenized muscle tissue from each of 10 individual fish. Values in parentheses are % relative standard deviations. Entries in rows sharing the same superscript letter are not statistically different ($p < 0.05$) and are referred to as similarity groups; group numbers refer to numbers of similarity groups computed for each fatty acid.

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	Groups
	Concentration in wt %										
14:0	2.82 (5.54) ^a	4.14 (2.20) ^{cd}	4.43 (1.78) ^a	3.99 (1.85) ^{cd}	2.85 (8.12) ^{ab}	4.30 (1.93) ^{cd}	4.38 (5.02) ^{cd}	2.89 (4.83) ^{ab}	3.01 (0.830) ^b	3.91 (2.77) ^a	5
16:0	22.0 (5.10) ^a	18.8 (1.68) ^a	19.0 (1.99) ^a	20.0 (1.68) ^{ab}	18.4 (5.21) ^a	19.6 (0.467) ^a	20.0 (0.910) ^{cd}	19.1 (3.72) ^a	18.1 (1.92) ^a	21.4 (1.28) ^{bc}	3
18:0	7.18 (2.22) ^a	2.99 (5.07) ^a	3.48 (3.81) ^{ab}	4.40 (3.61) ^{cd}	6.19 (1.75) ^a	3.66 (2.36) ^b	3.94 (7.14) ^{abc}	5.55 (3.50) ^a	6.71 (0.323) ^{cd}	4.46 (6.25) ^a	7
20:0	0.255 (3.65)	0.255 (3.65)	0.251 (3.60)	0.231 (2.89)	0.354 (3.35)	0.219 (1.10)	0.341 (45.6)	0.345 (3.72)	0.237 (2.15)	0.215 (8.01)	1
22:0	0.585 (3.07)	0.585 (3.07)	0.478 (28.7)		0.644 (3.52)					0.427 (22.0)	1
16:1	18.2 (9.48) ^a	38.1 (0.957) ^a	35.3 (1.12) ^a	27.6 (1.22) ^{cd}	21.1 (2.94) ^a	34.8 (0.275) ^a	30.5 (0.702) ^d	28.1 (6.77) ^{bc}	25.8 (7.04) ^b	28.9 (2.61) ^{cd}	6
18:1	5.67 (1.06) ^{ab}	5.87 (7.28) ^b	6.66 (4.65) ^{cd}	5.68 (1.43) ^{ab}	6.17 (1.99) ^{cd}	6.57 (1.35) ^{cd}	6.69 (3.98) ^{cd}	5.17 (3.32) ^a	6.08 (3.09) ^{bc}	6.79 (3.05) ^d	5
20:1	0.991 (0.469) ^a	1.20 (10.9) ^d	0.945 (2.36) ^{bc}	1.07 (3.69) ^{cd}	2.10 (2.09) ^a	1.04 (0.379) ^{cd}	0.773 (10.8) ^b	0.441 (1.88) ^a	1.06 (11.1) ^{cd}	0.775 (4.15) ^d	4
22:1	1.30 (4.84) ^a	1.30 (4.84) ^a	0.874 (28.2) ^a	0.393 (8.45) ^{ab}	0.732 (0.968) ^{cd}	1.83 (4.53) ^a	0.631 (20.7) ^{cd}	0.297 (5.48) ^a	0.423 (31.8) ^{abc}	0.504 (6.65) ^{abc}	6
18:2n-6	0.699 (7.71) ^{ab}	1.30 (10.3) ^a	1.23 (6.62) ^{bc}	1.71 (5.08) ^a	0.950 (10.0) ^a	0.965 (3.75) ^a	2.27 (9.14) ^a	1.68 (12.3) ^d	1.47 (1.89) ^{cd}	1.99 (1.90) ^d	5
18:3n-3	0.606 (5.27) ^{abc}	0.452 (3.81) ^{ab}	0.518 (14.6) ^{abc}	1.36 (0.863) ^b	0.553 (0.377) ^{abcd}	0.373 (0.560) ^{abc}	0.783 (14.9) ^{cd}	0.678 (1.92) ^d	0.879 (12.0) ^d	0.722 (10.9) ^{cd}	7
20:2n-6	0.407 (6.37) ^a	0.147 (3.97) ^{ab}	0.228 (1.70) ^{abc}	0.288 (28.8) ^{abcd}	0.571 (15.9) ^a	0.108 (13.0) ^a	0.390 (18.9) ^{cd}	0.316 (11.6) ^{abcd}	0.251 (18.8) ^{abcd}	0.147 (27.0) ^{ab}	6
20:3n-3	0.362 (4.60) ^{abc}	0.423 (15.1) ^{ab}	0.385 (2.16) ^{abc}	0.317 (5.49) ^{abc}	0.435 (4.05) ^b	0.318 (2.54) ^{abc}	0.433 (27.2) ^a	0.292 (11.7) ^{ab}	0.278 (1.15) ^a	0.300 (1.44) ^{ab}	3
20:4n-6	4.90 (1.81) ^a	3.15 (0.809) ^d	3.53 (2.34) ^a	3.09 (2.84) ^d	7.00 (1.07) ^a	1.70 (0.872) ^a	1.84 (4.29) ^a	3.68 (3.46) ^a	2.72 (4.20) ^a	2.15 (1.56) ^a	7
20:5n-3 (EPA)	13.4 (1.30) ^a	9.85 (2.10) ^a	9.85 (1.46) ^a	11.4 (0.354) ^{cd}	11.7 (2.19) ^a	12.6 (0.374) ^a	10.9 (1.69) ^{bc}	10.8 (3.12) ^{bc}	11.8 (3.34) ^d	10.7 (1.93) ^a	5
22:2n-6	0.167 (1.45) ^a		0.205 (23.6) ^a	0.105 (19.8) ^a	0.145 (20.7) ^a	0.613 (28.4) ^b	0.170 (43.5) ^a	0.0833 (12.5) ^a	0.0496 (14.1) ^a		2
22:4n-6	0.689 (2.76) ^{cd}	0.942 (5.25) ^{cd}	0.897 (22.1) ^{cd}	0.477 (8.10) ^{abc}	1.13 (6.49) ^a	0.623 (1.78) ^{bc}	0.453 (16.4) ^{ab}	0.474 (17.0) ^{abc}	0.325 (12.9) ^a	0.267 (0.618) ^a	6
22:5n-3	3.94 (10.9) ^a	3.53 (3.52) ^{abc}	3.80 (0.877) ^{bc}	3.69 (3.05) ^{bc}	4.86 (6.42) ^d	3.89 (0.423) ^a	3.26 (1.79) ^{ab}	2.99 (3.52) ^a	3.41 (5.63) ^{abc}	3.66 (2.45) ^{bc}	4
22:6n-3 (DHA)	18.0 (11.4) ^a	6.00 (4.51) ^a	7.24 (1.01) ^a	13.7 (3.35) ^a	13.6 (9.46) ^b	5.50 (1.39) ^a	11.6 (1.13) ^a	18.6 (4.03) ^a	16.9 (3.87) ^a	12.5 (2.32) ^a	3
ΣP:UFA	43.4 (5.63) ^a	25.8 (1.13) ^a	27.9 (0.249) ^a	36.2 (1.14) ^a	41.0 (4.55) ^{ab}	26.8 (0.554) ^a	32.1 (0.009) ^b	39.7 (3.69) ^{cd}	38.1 (3.60) ^{cd}	32.1 (1.74) ^b	5
Σsaturates	31.7 (4.41) ^a	26.7 (1.24) ^a	27.6 (1.44) ^{ab}	28.6 (1.782) ^{cd}	28.5 (4.37) ^{ab}	27.7 (0.236) ^a	28.6 (0.605) ^{ab}	27.9 (2.39) ^a	28.1 (1.37) ^a	30.4 (0.896) ^{bc}	3
Σmonounsaturates	24.9 (7.00) ^a	47.5 (0.573) ^b	43.8 (0.546) ^b	34.7 (0.782) ^{cd}	30.0 (2.18) ^a	44.3 (0.147) ^a	38.6 (0.274) ^a	32.0 (5.97) ^{bc}	33.4 (5.28) ^a	37.0 (2.18) ^{cd}	7
Σunsat/Σsat	2.16 (6.58) ^a	2.74 (1.69) ^a	2.53 (1.18) ^{cd}	2.44 (1.98) ^{bc}	2.46 (6.04) ^a	2.46 (0.959) ^a	2.42 (0.623) ^{bc}	2.54 (3.33) ^{cd}	2.51 (1.91) ^a	2.23 (1.16) ^{cd}	4
Σn-6	5.42 (2.22) ^a	4.61 (2.63) ^a	5.19 (2.22) ^a	5.19 (2.21) ^a	8.68 (1.10) ^a	4.68 (2.96) ^a	4.68 (2.96) ^a	5.77 (3.46) ^a	4.50 (4.23) ^a	3.99 (0.127) ^a	7
Σn-3	36.9 (6.59) ^a	21.2 (1.87) ^a	22.7 (0.444) ^a	31.0 (1.69) ^{cd}	32.4 (5.86) ^a	23.6 (0.394) ^a	27.5 (0.425) ^b	33.9 (4.07) ^{cd}	33.8 (3.51) ^{cd}	28.1 (1.89) ^{cd}	5
Σn-3/Σn-6	5.76 (7.56) ^a	4.61 (4.33) ^a	4.37 (4.42) ^{ab}	5.67 (3.94) ^a	3.78 (6.42) ^a	7.18 (4.96) ^d	5.68 (3.41) ^a	5.88 (2.45) ^a	7.49 (0.733) ^{cd}	7.05 (1.80) ^d	4
(EPA+DHA)/n-3, %	84.9 (0.460) ^a	74.8 (0.447) ^a	75.3 (0.844) ^a	81.1 (0.604) ^a	78.1 (0.276) ^b	77.9 (0.165) ^{cd}	82.1 (0.165) ^{cd}	86.9 (0.195) ^a	85.4 (0.441) ^a	82.4 (0.348) ^a	6

DISCUSSION

The polyunsaturated fatty acids in all fish lipids (both n-3 and n-6) are derived solely from the diet, but ultimately are of plant origin. In general, plants synthesize all of their fatty acids, and phytoplankton is the basic food in the aquatic field. Those species that feed directly on plant material (phytoplankton and algae) reflect those plant fatty acids, while higher order carnivores accumulate n-3 and n-6 PUFA contained in their prey which have progressed through the food chain from the original plant source (Sargent, 1976; Sargent and Whittle, 1981). Red and brown macroalgae found in both the northern and southern hemispheres are rich in arachidonic acid and EPA (Jamieson and Reid, 1972). Dunstan *et al.* (1988) reported high concentrations of both EPA and arachidonic acid in finfishes who feed on macroalgae in temperate Australian waters which is consistent with findings of Evans *et al.* (1986); high levels of both fatty acids were also observed with the striped mullet in this study. Gibson *et al.* (1984) reported fatty acids in 24 Australian finfishes, of which only the members of the mullet family (Mugilidae), whiting, turbot and leatherjacket had higher EPA concentrations than DHA. A diet containing macroalgae may help explain the elevated levels of both arachidonic acid and EPA in the striped mullet.

The pronounced variability in the fatty acid levels in individual striped mullet is most likely due to inclusion of detrital material in the diet, rather than the macroalgae. Organic detritus in estuarine waters and sediments is composed primarily of small amorphous aggregates which may originate from several sources, including benthic microalgae, phytoplankton, microbes and aggregates of dissolved organic carbon excreted or leached from plants and animals as well as salt marsh plants (Boesch and Turner, 1984). Organic carbon in estuarine sediments is extremely variable (Lytle and Lytle, 1985) and would account for the more highly variable diet of striped mullet which is derived in large measure from sedimentary organic matter.

Spot feed almost exclusively on invertebrates, primarily marine polychaetes and small bivalves. Because of their selective feeding habits, their diet is more consistent than the diet of striped mullet, particularly those feeding in the same areas. Marine polychaete worms, a dietary item of spot but not mullet, contain high concentrations of n-3 PUFA with EPA (20:5n-3) concentrations much higher than DHA (22:6n-3) (Lytle and Lytle, 1990a). Similarly, EPA concentrations were higher than DHA concentrations in the individual spot. Over 90% of 40 species of Gulf finfishes analyzed in our laboratory (Lytle and Lytle, 1990b) contained higher concentrations of DHA than EPA. Spot was one of the exceptions.

Saturated fatty acids, both individually and as a class, are conservative, i.e. are relatively constant and in this case demonstrate little fluctuation in level and distribution among individuals of either spot or striped mullet. On the other hand, the monounsaturates, both individually and as a class, exhibited a wider variation among the individual fish for both species. Individual striped mullet showed a considerable range in 16:1 concentrations; again, this could be a result of the broad spectrum of plant and detrital material in the diet. The narrower range of concentrations of 16:1 among individual spot may reflect the consistent invertebrate diet.

Arachidonic acid, the major n-6 PUFA found in both spot and mullet, was one of the most variable constituents in mullet, producing seven statistically similar groups with four groups in spot. That variation provides strong evidence that this n-6 PUFA is a non-conservative component in both species. High proportions as well as high variability of arachidonic acid are characteristic of tropical Australian marine fish and shellfish (Gibson, 1983; Sinclair, 1983). However, significant levels have been reported in some northern hemisphere fish (Kinsella *et al.*, 1977; Gunstone *et al.*, 1978; Gibson *et al.*, 1984; Gooch *et al.*, 1987).

In summary, the results of this study, based upon a small but selective group of fish, indicate that each constituent fatty acid as well as fatty acid class varies in individuals within a species of marine fish, even when all environmental and physiological effects are minimized. The extent of individual fish variation differs between the two species that were studied, with striped mullet showing much greater variability in fatty acid composition and lipid content than did individual spot. Diet is most likely the primary cause of variations in individual fish, and a more diverse diet probably accounts for the accentuation in individual variability in striped mullet. It is possible that samples collected from other locales or during another season would have shown entirely different trends. This can only be established from more definitive investigations on the composition of fish diets under a variety of fish collection conditions.

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LONG-TERM STUDY OF BENTHIC COMMUNITIES ON THE CONTINENTAL SHELF OFF CAMERON, LOUISIANA: A REVIEW OF BRINE EFFECTS AND HYPOXIA

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ABSTRACT A long-term data set compiled from our studies and a variety of investigations was analyzed to determine the effects of nine years of discharged brine (concentrated salt water) on benthic organisms surrounding a brine diffuser off Cameron, Louisiana (USA). These investigations began three months before brine discharge was initiated in 1981. A preliminary summary by Giammona and Darnell (1990) relied on just three years of discharge data and gave misleading reports of brine impacts.

Brine effects over the nine years of study were minimal, in part because the fine sediments of the study area were numerically dominated by opportunistic species, mostly estuarine taxa, that showed dramatic population fluctuations both spatially and temporally. These fluctuations in benthic densities were the most salient characteristic of the study area. They resulted from summer hypoxia and anoxia in bottom waters, not from brine. The hypoxia was related to Mississippi River discharge and subsequent salinity stratification. Hypoxia eliminated some taxa and severely reduced populations of most benthic species. The only significant differences between communities near the diffuser and those outside the influence of its discharged brine resulted from water-column mixing by the discharged brine, which oxygenated waters around the diffuser and stabilized the salinity of bottom water at the stations near the diffuser. This enhanced benthic diversity around the diffuser and resulted in greater populations during some seasons.

INTRODUCTION

The United States established the Strategic Petroleum Reserve (SPR) following the 1972 Middle East oil embargo to ensure adequate oil reserves and prevent future petroleum shortages in the United States. The SPR designed and implemented a plan for storage of approximately 1 billion bbl of crude oil in underground caverns hollowed from salt domes along the U.S. Gulf Coast. These caverns were created and subsequently enlarged by high-pressure jets of water blasted against cavern walls, producing up to 80 million liters (1 million bbl) of saturated brine per day that was pumped into the ocean.

The purpose of this study was to assess long-term effects of discharged brine on the macrobenthic communities surrounding the diffuser, in water approximately 10 m deep. Giammona and Darnell (1990) reported an impact of brine on the benthic communities during 1981 - 1983, and suggested that the communities might return to background levels once discharge ceased. Gaston *et al.* (1985) studied colonization near the discharge site during 1982, and concluded that there were no obvious effects of brine on functional feeding groups of benthos. Data were collected on benthic communities surrounding the West Hackberry brine diffuser during 1981 - 1984 and 1988 - 1989 to test the hypothesis that the macrobenthic-community species com-

position and taxon abundance in the area of the diffuser returned to background levels by 1988 - 1989 by comparing benthic community data near the diffuser and at several distances away.

Background

The U.S. Department of Energy (DOE) began discharging saturated brine (salt water up to 150 ppt) into the Gulf of Mexico from its SPR West Hackberry site during May 1981. There were several SPR sites established along the Louisiana and Texas coasts. West Hackberry was an SPR site located near Hackberry, Louisiana, just inland of the coastal fishing city of Cameron, Louisiana. Brine was pumped from salt-dome caverns to a holding pond, then to a discharge site in the Gulf of Mexico approximately 11.5 km southwest of Calcasieu Pass, near Cameron, Louisiana. The brine entered the Gulf through diffuser heads at the end of a pipeline. The brine was generally comparable to sea water in ionic ratios, except for slightly higher calcium and slightly lower magnesium concentrations (Jeffrey *et al.*, 1983). Except for short-term shutdowns, the discharge was continuous at rates of 40 to 80 million liters/day until November 1984. Brine flow thereafter occurred irregularly, and discharge volume varied widely through 1989.

However, some discharges occurred every year at rates of up to 80 million liters/day.

The area was first studied for an environmental impact report by Science Applications Incorporated (1976). A second study was conducted by the U.S. Department of Commerce (1981), and a review by Parker *et al.* (1980) included macrobenthic communities surrounding all proposed brine disposal sites in the Gulf of Mexico. A comprehensive study of the local macrobenthic community was conducted by Weston and Gaston (1982), who established the long-term sampling sites during the three months prior to the initiation of brine discharge. The effects of first year brine discharge on the macrobenthic communities were addressed in a multidisciplinary study by Gaston and Weston (1983). Gaston (1985) and Gaston *et al.* (1985) investigated the trophic structure and recolonization capabilities of macrobenthic organisms in the area of the brine plume. Benthic investigations centered on comparisons of community parameters near the diffuser with those at various distances away, including comparisons with reference sites outside the plume of discharged brine.

Gaston and Weston (1983) and Hann *et al.* (1985a) reported a significantly greater abundance of benthic organisms and greater numbers of species near the diffuser, in part due to the elimination of all benthos at sampling sites outside the brine plume during summer hypoxia (Gaston, 1985). Physical mixing of the water column by the diffuser apparently disrupted stratification of the water column and kept the bottom water and sediments around the diffuser oxygenated. Giammona and Darnell (1990) erroneously referred to this discrepancy in community parameters as a "long-term cumulative effect" of discharge, and suggested that benthic communities around the diffuser might return to background levels once brine discharge ceased. We collected data under the auspices of the Louisiana Department of Wildlife and Fisheries (LDWF) during 1988 - 1989.

Study Area

The study area centered around the West Hackberry brine diffuser located on the continental shelf off Cameron, Louisiana (Figure 1).

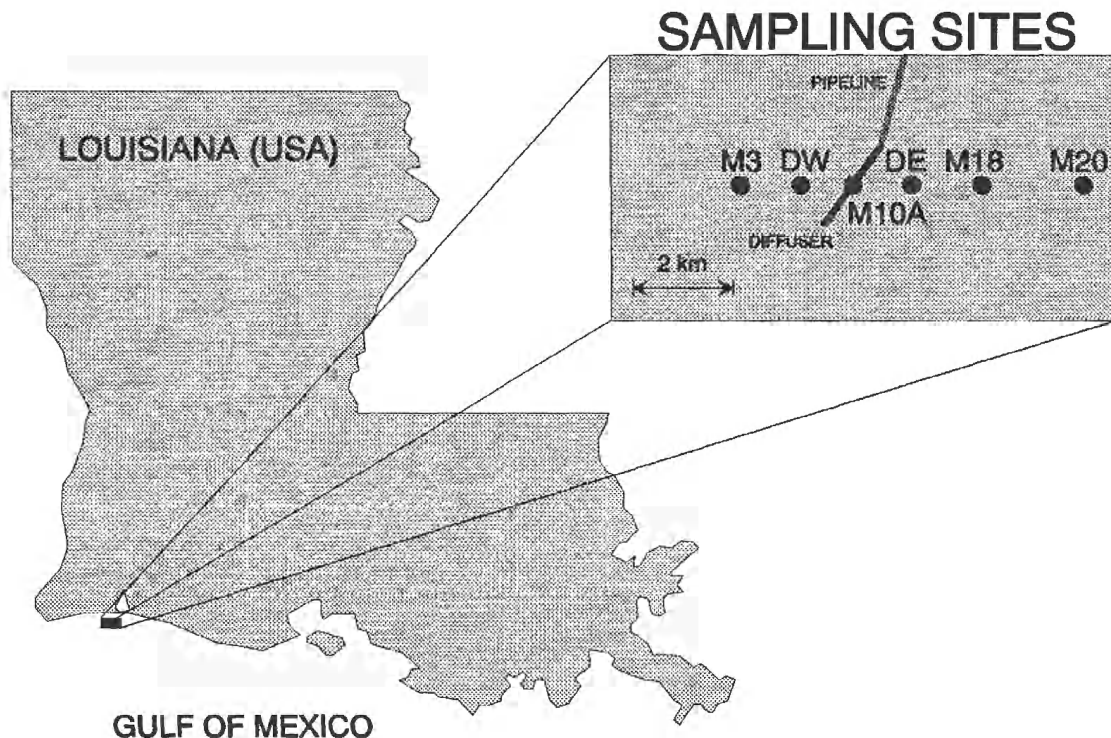


Figure 1. Sampling sites located in a transect across a Strategic Petroleum Reserve (SPR) brine diffuser in the Gulf of Mexico off Cameron, Louisiana. All stations were located at 10-m water depth. Brine was pumped to the diffuser from the West Hackberry SPR facility.

The physical environment of the study area was described by Hann *et al.* (1985a) and Gaston *et al.* (1985). Sediments of the area were generally silty sand (50 - 90% silt-clay). Bottom salinity (15 - 32 ppt) ranged widely with season and tidal cycles, due to the proximity of the Calcasieu, Atchafalaya, and Mississippi Rivers. Temperatures of bottom water varied from winter lows of approximately 12°C to 30°C during the summer. Water currents varied with wind speed and direction, but westerly currents dominated, thereby generally moving the brine plume west of the diffuser site (M10A) and away from the control site (M20) (Gaston and Weston, 1983; Gaston *et al.*, 1985; Hann *et al.*, 1985a).

Bottom oxygen levels during summer months often dropped below 2 ppm (hypoxia) and periodically reached anoxic conditions (Gaston, 1985). Hypoxia occurred during summer months of most years, although it was periodically disrupted by strong winds or storms. Hypoxia had a dramatic effect on benthic communities in the study area, depleting benthic populations, and resulting in domination by relatively small benthos and first-year populations (Gaston, 1985; Gaston *et al.*, 1985).

MATERIALS AND METHODS

Six stations (DE, DW, M3, M10A, M18, and M20) were sampled along an east-west transect across the diffuser (Figure 1). All stations were at 10 m depth. Samples were taken monthly during 1981 and 1982, and less often thereafter. The eastern-most site (Station M20) was located 10 km east of the diffuser, and was outside the effects of discharge (Gaston and Weston, 1983). Station M18 was 5 km east of the diffuser and rarely within the brine plume. The other four sites were within the plume fairly regularly, depending on their distance from the diffuser, the discharge rate, and prevailing currents. Lower water-column salinity near the diffuser was generally 3 - 8 ppt above ambient due to brine discharge (Hann *et al.*, 1985a).

Six replicate samples were taken at each station. Number of replicates necessary to assess the macrobenthic communities of the study area was determined by Gaston and Weston (1983). Samples were taken with a 0.1 m² Smith-McIntyre sediment grab, washed on a 0.5 mm sieve, preserved in buffered formalin in the field, and transferred to 70% ethanol in the laboratory. Most specimens were identified to species.

Statistical analyses included a Model I Analysis of Variance (ANOVA, Sokal and Rohlf, 1981) among stations (when the Bartlett Test indicated homogeneity of variance) using dominant-species densities and total numbers of macrofauna in each replicate as entities. If statistically significant differences were indicated by ANOVA, Duncan's

Multiple Range Tests were used to test for statistical differences ($\alpha = 0.05$) among stations. Additional information concerning the study area, its physical regime, and methods of sampling was provided by Gaston and Weston (1983), Gaston (1985), and Gaston *et al.* (1985).

RESULTS AND DISCUSSION

There were no notable changes in the sedimentary regime of the study area following the initiation of brine discharge (Hann *et al.*, 1985a). Sediments consisted primarily of silty clay to sandy mud, with never more than 48% sand at any site.

During the entire study period, the benthic community was characterized by strong numerical dominance of relatively few species that showed dramatic population fluctuations both spatially and temporally. Most noteworthy among the species that numerically dominated prior to brine discharge were deposit-feeding polychaetes (especially *Sabellides* sp.) and a suspension-feeding phoronid, *Phoronis muelleri* (Weston and Gaston, 1982). Weston and Gaston concluded that the dominance by opportunistic species lessened the potential for assessment of impact from brine, even though there was a general homogeneity of the benthic faunal distributions in the area. Populations of opportunistic species are characterized by wide fluctuations in densities.

During the first year following initiation of brine discharge, the benthic communities showed no changes that could be attributed to brine impact (Weston and Gaston, 1982). The macrobenthic communities of the area were dominated by a rapidly changing suite of young individuals of opportunistic species, mostly detritivores (Gaston and Weston, 1983). Suspension-feeding and deposit-feeding polychaetes, such as *Magelona* cf. *phyllisae*, *Paraprionospio pinnata*, *Mediomastus californiensis*, and *Cirratulus* cf. *filiformis* dominated. Gaston and Weston (1983) reported higher numbers of species and higher populations of some taxa around the brine diffuser ($P \leq 0.05$), believed related to salinity stability near the diffuser. Populations of *M. cf. phyllisae* were significantly higher around the diffuser during six of the twelve months following initiation of discharge. *Mediomastus californiensis* populations were also periodically elevated around the diffuser (Station M10A) during the first year of discharge, but matched background levels thereafter.

There were predictions that discharged brine might be toxic to planktonic larvae of the benthos. Indeed, Vecchione *et al.* (1983) reported reduced numbers of zooplankton and some sublethal effects on zooplankton near the diffuser. Colonization studies of macrobenthos were subsequently conducted by placing defaunated sediment boxes in areas

near the diffuser and outside the brine plume (Gaston *et al.*, 1983; Gaston *et al.*, 1985). These studies indicated that most colonization of the sediments resulted from settling meroplanktonic larvae, the macrobenthos in the area of the brine diffuser rapidly colonized, and no significant differences were found between the diffuser and control sites.

Perhaps the most salient aspect of the West Hackberry SPR diffuser study area was apparent by 1981. The diffuser was located in an area of the northern Gulf of Mexico continental shelf affected by summer hypoxia which annually eliminated much of the benthic community, thus leading to domination by first-year benthos (Gaston, 1985). The dominant species of the area following hypoxic conditions was most commonly the polychaete, *Magelona* cf. *phyllisae*, perhaps indicative of its tolerance to high levels of hydrogen sulfide and low dissolved oxygen. All of the dominant species in the area were opportunistic species. There was often higher abundance and more species at stations surrounding the diffuser, Station M10A (Tables 1-2). Gaston (1985) proposed that the differences between communities near the diffuser and those outside the brine plume resulted from effects of hypoxia and brine discharge, especially physical mixing of the water column by the diffuser, resulting in breakup of density stratification, and stabilization of the bottom salinity surrounding the diffuser. Salinity stability in an area with widely fluctuating tidal conditions may lead to higher diversities and colonization by more high-salinity taxa (Gaston *et al.*, 1985). As a result, populations of many taxa surrounding the diffuser survived hypoxic events of 1982, and many high-salinity taxa colonized the area around the diffuser (Gaston and Weston, 1983; Gaston, 1985; Gaston *et al.*, 1985).

No major impacts to the macrobenthic community from brine discharge were detected during 1983 - 1984 (Hann *et al.*, 1985a). Summer hypoxia again was the primary factor in structuring benthic communities of the area. Hann *et al.* (1985a) reported that sediments matched predischARGE conditions, species diversity was highest at the diffuser site, and greater abundance of macrofauna often occurred around the diffuser (Tables 1 - 2). Giammona and Darnell (1990) referred to these differences between diffuser and control sites as an "impact"; however, the term "impact" was misleading, since the effect was a reduced impact from hypoxia, rather than a toxic effect of brine discharge. Giammona and Darnell further hypothesized that benthic-community characteristics should return to background levels once brine discharge ended.

Abundance of macrobenthos in the study area varied widely during 1981 - 1984 (Tables 1 - 2). During the summer of 1981, abundance was reduced by hypoxia at every station, though the effects were generally lessened around the diffuser as evidenced by greater number of taxa surviving at Station M10A (Table 2; Gaston, 1985). Numbers at one site (M3) reached over 20,000 individuals m⁻²

during June 1981, but dropped below 1000 individuals m⁻² elsewhere (M18) following the 1981 summer hypoxia. Hypoxia was not as persistent during summer of 1982; abundance that summer was higher at most stations (2000-3000 individuals m⁻²). Hypoxia again eliminated most macrobenthos during summer of 1983 and 1984, and communities dropped to below 1000 individuals m⁻² at most sites (Hann *et al.*, 1985a).

Macrobenthic densities and taxa collected during summer 1988 - 1989 (Table 3) were similar to those reported soon after the initiation of brine discharge by Gaston and Weston (1983), Hann *et al.* (1985a), Gaston (1985), and Gaston *et al.* (1985). Abundance during summer (1988 - 1989) was low; fewer than 1000 individuals m⁻² occurred at some sites during August 1988. During August 1989, however, densities at all sites exceeded 2000 individuals m⁻², perhaps indicative of lessened effects of hypoxia. There were no differences in numbers of taxa or number of individuals ($P > 0.05$) between diffuser and control stations during 1988; however, there were elevated numbers of individuals around the diffuser during 1989. These 1989 data suggest that the brine diffuser may have enhanced colonization by benthic communities or reduced effects of dissolved oxygen.

Opportunistic species, primarily estuarine polychaetes, were numerically dominant throughout the study, and there were no substantial changes in the functional feeding groups during the nine-year period. Suspension-feeding and deposit-feeding polychaetes, especially *Magelona* cf. *phyllisae* and *Paraprionospio pinnata*, dominated throughout the study. The phoronid, *Phoronis muelleri*, and polychaetes, *Sabellides* sp. and *Cirratulus* cf. *filiformis*, that were so abundant during the early 1980s diminished in mean density to below five individuals m⁻² at every site by 1989. Other opportunistic polychaetes, *Cossura soyeri* and *Sigambra tentaculata*, increased in abundance during the late 1980s. Such shifts among dominant taxa are common in many continental shelf macroinvertebrate communities (reviewed by Gaston, 1987; Parker *et al.*, 1980) and was reported in previous investigations of the area (Gaston and Weston, 1983; Gaston, 1985; Gaston *et al.*, 1985).

Large molluscs and other equilibrium (long-lived) species were never collected. Juveniles of the bivalve mollusc, *Mulinia lateralis*, dominated the taxa at most stations during June 1988 (mean of 476 m⁻²; up to 1066 m⁻²), but were eliminated by August 1988 and were not abundant during August 1989. This species often was among the numerically dominant taxa during late winter and spring of the early 1980s, but its populations were eliminated or severely reduced during summer hypoxia (Gaston and Weston, 1983; Gaston, 1985; Hann *et al.*, 1985a). Other molluscs that were severely impacted by hypoxia included *Epitonium* sp., *Anachis obesa*, *Nassarius vibex*, *N. acutus*, and *Macoma mitchelli*. A similar pattern of colonization

TABLE 1

Average abundance ($n = 6$) of macrobenthos (m^{-2}) by month and by year. Collections were made at the West Hackberry brine discharge study area off Cameron, Louisiana. No collection of data is indicated by a dash. Data from Gaston (1985, 1992), Gaston *et al.* (1985), and Hann *et al.* (1985).

1981	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
M3	2952	6747	10478	14620	21790	6220	4780	2830	2360	2130	71540	
DW	3605	3487	4795	4520	3300	2780	2040	1710	1830	1510	1760	
M10A	3448	5463	4866	4980	13050	1020	1350	2050	2040	2520	3260	
DE	1622	4422	3597	3570	1830	980	1520	1730	2390	1610	2220	
M18	1843	4150	4222	3140	4190	2150	670	1680	1380	1940	2080	
M20	2808	3533	2445	1410	2740	-	-	2010	1720	1770	1830	
1982	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
M3	1890	3320	2740	5610	4753	2438	2360	2809	2062	-	4958	-
DW	1980	2890	3940	4890	4070	3579	1324	2251	1588	-	3621	-
M10A	1960	2940	4740	3910	6767	3575	3061	1420	2418	-	3403	-
DE	3070	4730	4730	5920	7918	4261	2326	3003	2234	-	2704	-
M18	2740	5410	3210	5880	5132	3656	2368	2649	2984	-	2632	-
M20	2910	6780	8840	6230	6844	1951	2019	1622	-	2123	-	-
1983	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
M3	-	5271	-	-	2428	1348	942	1790	-	-	1185	-
DW	-	11600	-	-	1515	685	857	887	-	-	1635	-
M10A	-	10025	-	-	703	800	1079	907	-	-	1663	-
DE	-	4696	-	-	745	1403	1488	1266	-	-	1579	-
M18	-	18736	-	-	1064	1032	1164	1538	-	-	1425	-
M20	-	2589	-	-	1304	583	952	775	-	-	1246	-
1984	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
M3	-	2038	-	-	541	636	1411	1115	-	-	1046	-
DW	-	2387	-	-	2827	1282	1693	1093	-	-	1523	-
M10A	-	4503	-	-	1057	950	1579	874	-	-	1159	-
DE	-	2287	-	-	1248	1833	2055	1324	-	-	1015	-
M18	-	1877	-	-	782	226	1668	1311	-	-	2368	-
M20	-	1331	-	-	865	2375	743	978	-	-	1862	-

TABLE 2
Number of macrobenthic taxa (total in six replicates) by month and by year. Collections were made at the West Hackberry brine discharge study area off Cameron, Louisiana. No collection of data is indicated by a dash.

1981	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
M3	-	47	51	47	48	47	29	41	50	55	50	54
DW	-	43	42	55	58	65	28	40	40	53	48	49
M10A	-	53	49	50	53	76	35	53	39	48	48	47
DE	-	35	41	53	54	48	36	36	34	52	51	52
M18	-	35	46	49	45	41	28	25	37	40	43	42
M20	-	41	41	39	45	50	-	-	32	42	38	36
1982	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
M3	53	68	56	64	70	52	43	54	49	-	61	-
DW	42	49	53	49	46	36	36	53	41	-	45	-
M10A	49	50	48	52	54	49	59	50	56	-	47	-
DE	46	47	65	49	49	40	47	52	44	-	46	-
M18	47	53	40	51	47	29	46	42	46	-	36	-
M20	47	49	54	45	56	47	38	48	44	-	44	-
1983	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
M3	-	64	-	-	37	18	12	24	-	-	61	-
DW	-	50	-	-	26	23	23	23	-	-	53	-
M10A	-	60	-	-	24	32	46	31	-	-	66	-
DE	-	41	-	-	23	31	23	26	-	-	43	-
M18	-	40	-	-	23	25	19	18	-	-	49	-
M20	-	41	-	-	25	21	16	25	-	-	44	-
1984	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
M3	-	85	-	-	54	71	39	43	-	-	61	-
DW	-	65	-	-	37	34	39	39	-	-	24	-
M10A	-	78	-	-	49	48	66	73	-	-	65	-
DE	-	65	-	-	36	34	61	43	-	-	36	-
M18	-	54	-	-	37	48	49	29	-	-	24	-
M20	-	56	-	-	29	34	29	26	-	-	26	-

TABLE 3

Number of macrobenthic taxa (total in six replicates) and mean densities (m^{-2}) at six stations during sampling periods in 1988 and 1989. Collections were made at the West Hackberry brine discharge study area off Cameron, Louisiana. Values with similar superscript letters are not significantly different ($P > 0.05$).

		M3	DW	M10A	DE	M18	M20
June 1988	TAXA	58	63	43	57	37	42
	INDIV.	3372	3898	2065	3543	1660	1962
August 1988	TAXA	38	28	37	42	48	45
	INDIV.	977	872	1245	983	1530	1028
August 1989	TAXA	26	32	27	24	25	27
	INDIV.	2080 ^a	3945 ^a	5200 ^b	2775 ^a	4918 ^{ab}	3027 ^a

followed by elimination occurred among the brittle star species, *Hemipholis elongata*, which had been very abundant during the June 1988 sampling (mean of $460 m^{-2}$; up to $606 m^{-2}$), but was completely eliminated by August 1989.

CONCLUSIONS

Macrobenthic communities in the study area were not catastrophically impacted by brine discharge as was predicted (Science Applications Incorporated, 1976) before brine discharge began. It appeared that discharged brine had only minor effects on the macrobenthos of the West Hackberry SPR brine diffuser study area, and those effects were mostly enhancements of the benthic communities. Indeed, the only significant differences between communities near the brine diffuser and those outside the influence of its discharged brine resulted from turbulent mixing of the water column by the discharged water, which apparently also affected zooplankton (Vecchione *et al.*, 1983), decreased effects of hypoxia around the diffuser (Gaston, 1985), and stabilized the lower water-column salinity at the station closest to the diffuser (M10A) (Gaston *et al.*, 1985). Similarly, Hann *et al.* (1985b) found fewer species and lower abundance of benthos around the Bryan Mound diffuser during 1983–1984 and an enhancement of the communities at the near-field sites, but few consistent patterns of impacts of brine on the macrobenthos.

The hypothesis posed by Giammona and Darnell (1990) that benthic communities might return to background levels after brine discharge ended was erroneous.

Benthic communities surrounding the diffuser often matched background (control site) levels during discharge. Physical mixing of the water column and salinity stability due to brine discharge, both enhancement features of discharge operations, were the primary features that distinguished impact from control sites. Those distinctions resulted from greater densities of benthos within the affected area of the diffuser. Benthic communities around the diffuser did match background levels, except when those enhancement characteristics were in play.

The West Hackberry study area may be unique in many ways, and probably should not be used solely as an example of the potential for brine effects in other areas. Other offshore brine discharge sites were probably not so fortuitously placed. The Bryan Mound SPR site off Freeport, Texas was located in deeper water (21 m depth), had a more diverse and well-established macrobenthic community, and was not affected annually by hypoxia (Hann *et al.*, 1985b).

Summer hypoxia in the West Hackberry study area, without question, was the primary factor in structuring benthic communities. Hypoxia occurred almost annually, and so severely affected the benthic communities of the study area that brine effects were difficult to assess, especially since the brine effects appeared to be minimal. Hypoxia led to wide seasonal variations in populations of macrobenthos in the study area, and confounded year-to-year comparisons of brine effects (Gaston, 1985; Gaston *et al.*, 1985). Gaston *et al.* (1985) used the colonization study to investigate brine effects within the immediate area of the diffuser, and concluded that effects of brine were minor compared to the impact of hypoxia.

This study emphasized the necessity of long-term assessments of potential contaminants on benthic communities. The analyses were especially enhanced by multidisciplinary research projects in the area, manipulative studies of brine effects on colonization potential of settling larvae, investigations on macrobenthic functional-feeding groups, and intensified sampling efforts during hypoxic events that helped distinguish the effects of brine and hypoxia.

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Hepatocellular Neoplasm in a Wild-Caught Sheepshead Minnow (*Cyprinodon variegatus*) from the Northern Gulf of Mexico

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HEPATOCELLULAR NEOPLASM IN A WILD-CAUGHT SHEEPSHEAD MINNOW (*CYPRINODON VARIEGATUS*) FROM THE NORTHERN GULF OF MEXICO

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INTRODUCTION

The sheepshead minnow, *Cyprinodon variegatus*, is a widely distributed small fish species that inhabits estuaries and inshore waters from New England to northern South America. This species has been used extensively in aquatic environmental toxicity and carcinogenicity tests (Couch *et al.*, 1981; Courtney and Couch, 1984). Hepatic neoplasms have been induced in the sheepshead minnow by exposure to several known chemical carcinogens including diethylnitrosamine (Couch and Courtney, 1987), methylazoxymethanol acetate (Hawkins *et al.*, 1985), and dimethylbenz(a)anthracene (Hawkins *et al.*, 1991). Because of its widespread distribution, limited home range, and proven sensitivity to carcinogens, the sheepshead minnow appears to be a good candidate to serve as an *in situ* monitor of environmental carcinogens and other toxicants in coastal waters, especially those of the Gulf of Mexico and Caribbean Sea. To establish background information on the histopathological lesions in sheepshead minnows taken from the wild, we collected and examined specimens from an offshore site presumed to be free of chemical contamination. The present report concerns a hepatic neoplastic lesion, diagnosed as a hepatocellular adenoma, found in a wild sheepshead minnow. Neoplasms from wild sheepshead minnows or spontaneous neoplasms from laboratory specimens previously have not been reported.

MATERIALS AND METHODS

The collecting site was Big Lagoon on Horn Island in the Mississippi Sound approximately 18 kilometers from the mainland. Horn Island is part of the Gulf Islands National Seashore of the United States Park Service. About 300 specimens were collected by seining, returned to the laboratory under aeration, anesthetized with tricaine methanesulfonate (TMS), and examined for external lesions. After internal organs were examined for visible

lesions, the liver, gills, and kidney were removed, fixed in Lillie's solution (Humason, 1972) for 48 hours, washed in running water for 24 hours, stored in 70% ethanol at room temperature, cleared in Shandon xylene substitute (Shandon Inc., Pittsburg, PA) and embedded in paraffin following routine procedures. Sections were cut on a rotary microtome at 5 to 6 μ m thickness and stained with hematoxylin and eosin.

RESULTS AND DISCUSSION

A neoplastic lesion was found in the liver of a sheepshead minnow collected from Big Lagoon on Horn Island. No other signs of disease were observed. The specimen was a female estimated to be about one year old. In the plane of section in which it was detected, the neoplasm was 1.1 mm by 0.78 mm and occupied approximately 12% of the liver (Figure 1).

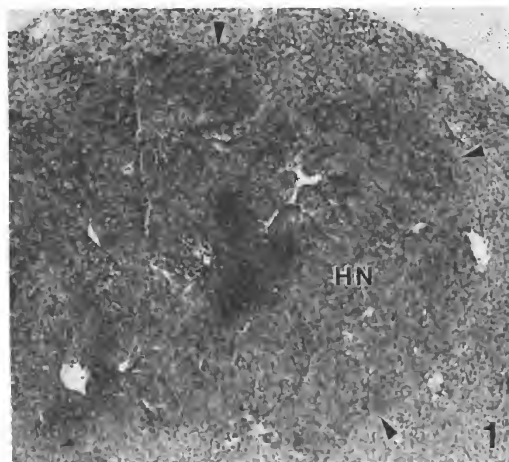


Figure 1. Low power micrograph showing hepatocellular neoplasm (HN) occupying a large portion of the liver of a sheepshead minnow. Arrowheads indicate border of lesion with surrounding normal tissue. Hematoxylin and eosin.

We diagnosed the lesion as a hepatocellular adenoma, but recognize that depending on the pathologist's particular criteria, a diagnosis of hepatocellular carcinoma might be justified. In our opinion, however, most of the criteria fit the diagnosis of adenoma. Cytologically, the lesion was well differentiated. That is, the organization and form of the cells in the lesion resembled those features in surrounding normal tissues (Figure 2). The neoplastic hepatocytes were larger and had larger nuclei than normal hepatocytes. Several mitotic figures were observed in the lesion (Figure 3). At its periphery, the lesion appeared to compress adjacent normal liver. No other neoplastic lesions were found in sections from specimens from that collection site.

Epizootics of hepatic neoplasms in fishes are highly correlated with environmental contamination (Harshbarger and Clark, 1990; Harshbarger *et al.*, 1993). Those authors considered an epizootic to be the occurrence of three or more cases of a neoplastic lesion from a specific cell lineage occurring in a single species from a defined geographic location. Although most neoplasm epizootics have involved large fish species, Vogelbein *et al.* (1990) recently reported epizootic hepatic neoplasia in a large percentage of mummichog (*Fundulus heteroclitus*) from a creosote-contaminated site along the Elizabeth River, VA. This present case of a hepatocellular neoplasm in a sheepshead minnow does not constitute an epizootic. The specimen

was collected from a site considered to be uncontaminated by chemicals. The lesion is significant, however, because it is the first report of a hepatic neoplasm in a wild sheepshead minnow and, possibly, is the first report of a hepatic neoplasm from a fish from the Gulf of Mexico. The occurrence of a single neoplasm-bearing specimen from over 300 examined fish could represent a spontaneous or background rate. Couch and Courtney (1987), however, reported no spontaneous liver neoplasms in several thousand sheepshead minnows examined over about 15 years. Nevertheless, the sensitivity of the sheepshead minnow to several carcinogens in laboratory and the widespread geographic distribution of the species suggest that the sheepshead minnow would be a good subject for surveys of aquatic environmental carcinogens in warm southern marine and estuarine waters.

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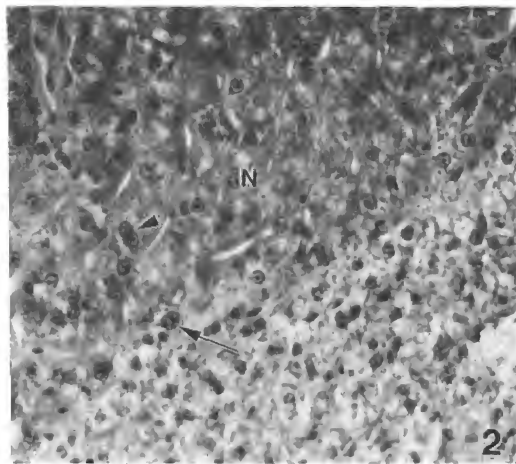


Figure 2. Higher power micrograph showing boundary between neoplastic cells (N) and normal surrounding tissue. Note binucleate cell (arrowhead) and enlarged nucleus (arrow) in lesion. Hematoxylin and eosin.

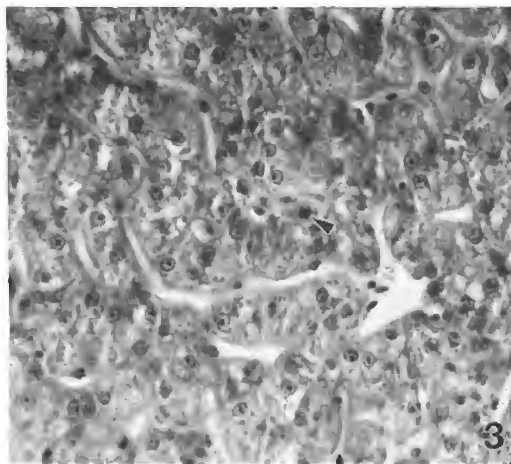


Figure 3. Mitotic figure (arrowhead) in lesion. Hematoxylin and eosin.

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The Scientific Publications of Charles Eric Dawson (1948-1990)

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THE SCIENTIFIC PUBLICATIONS OF CHARLES ERIC DAWSON 1948-1990

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INTRODUCTION

By the time Charles Eric Dawson died on February 11, 1993, he had produced a total of 150 published papers. His contributions represent an important chapter in the ichthyological investigations of marine fishes. His work on fishes of the Americas and on the taxonomy of pipefishes will long be remembered as two of his most significant and outstanding achievements. Although tribute to this Canadian-American Ichthyologist and longtime Senior Ichthyologist and Curator of the ichthyological research collection at the Gulf Coast Research Laboratory is presented elsewhere (Overstreet and Poss, *Copeia* 1993(3):921-925), it is appropriate that the extensive bibliography of one of GCRL's most productive scientists is compiled and made available to other researchers who will follow in his footsteps. These publications are listed chronologically.

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